NORTHRIDGE EARTHQUAKE

Turning Loss to Gain

Seismic Safety Commission
State of California

Report to the Governor

Governor's Executive Order W-78-94

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in response to
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SSC Report No. 95-01
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Seismic Safety Commission

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Preface

The Seismic Safety Commission is charged by statute to advise the Governor, the Legislature, local government, and the public on seismic safety. Recognizing this role, Governor Pete Wilson issued an executive order directing the Commission to study the Northridge earthquake and report on its policy implications for structural seismic safety and land use planning.

A disaster such as the Northridge earthquake puts great strain on state government and on the individuals who must respond. The Commission appreciates the generous spirit of dedication and cooperation displayed by the many agencies and individuals who participated in our review of the earthquake and its effects at a time when they needed most to attend to their own losses, jobs, and families. Thanks are also due to the Governor's Office of Emergency Services and the Federal Emergency Management Agency for providing the matching funds necessary for this review. The Commission believes the availability of these funds will allow California to build on the lessons learned from Northridge to reduce our losses in future earthquakes and responsibly manage the risk that remains.

Although the Commission believes California's seismic safety practices for building and land use are among the best in the world, there remain weaknesses that result in unacceptable risks to life and the economy. In light of these vulnerabilities, the Commission believes that California cannot continue with business as usual, particularly when there is the clear knowledge of the high likelihood that major earthquakes will strike our urban areas. This report recommends policy changes and implementation measures needed to lessen future losses.

In the end, it will be the will of the people, expressed through personal acts to mitigate earthquake risk as well as their support for earthquake programs, that will determine whether California attains an acceptable level of seismic safety by the end of this century.

Acknowledgments

The Seismic Safety Commission would like to thank Governor Pete Wilson for the opportunity to review the effects of the Northridge earthquake and the Federal Emergency Management Agency and the Governor's Office of Emergency Services for providing the financial support needed to prepare and distribute the report.

Without the cooperation and support of many design and construction professionals, as well as academia and federal, state, and local governmental agencies, this project could not have succeeded. The Commission appreciates the efforts of all who helped, including:

Local Governments

City of Los Angeles

City of Fillmore

City of Santa Monica

County of Los Angeles

State Agencies

Business, Transportation, and Housing Agency

Department of Housing and Community Development

Department of Transportation

Governor's Office of Emergency Services

California Office of Planning and Research

Health and Welfare Agency

Office of Statewide Health Planning and Development

Public Utilities Commission

Resources Agency

Office of Historic Preservation,
Department of Parks and Recreation

Division of Mines and Geology,
Department of Conservation

State and Consumer Services Agency

Building Standards Commission

Board of Registration for Professional Engineers and
Professional Land Surveyors

State Historical Building Code Board

Division of the State Architect,
Department of General Services

University of California

Federal Agencies

Federal Emergency Management Agency

United States Geological Survey

Private Organizations

American Institute of Architects, California Council

Associated General Contractors of California

California Building Industry Association

California Building Officials

California Fire Chiefs Association

California Institute of Technology

Consulting Engineers & Land Surveyors of California

Earthquake Engineering Research Institute

Southern California Earthquake Center

Southern California Gas Company

Structural Engineers Association of California

Among the dozens of individuals who reviewed and commented on draft materials, Robert Patrick, Frank E. McClure, and Barry Pascal gave extraordinary effort.

In addition, the Commission would like to thank Bruce Norton, ATI Consulting, for undertaking the difficult task as Project Director, and team leaders Kevin Coppersmith, William Holmes, J. Lawrence Mintier, and Joseph Penzien and their teams for their work on the *Compendium of Background Reports on the Northridge Earthquake*, published as Seismic Safety Commission Report No. SSC-94-08, which provided much of the information on which the Commission based the recommendations in this report.

A special thanks for their dedication, long hours, and hard work are also due to the Commission's staff, especially to Deborah Penny for formatting the document and to Brenda Boswell for editing it. The Commission also extends its appreciation to Jodi Adkins-Weast, Adkins Design, for her work on the report's design, illustrations, and layout.

Executive Summary

California is a remarkable place in which to live and work. In spite of its earthquake hazards, its residents are relatively safe from earthquakes. Its building stock and lifelines and the people and programs that address its earthquake risk are among the best in the world.

Californians are fortunate that seismic codes have been written and enforced here for the last half century, making California buildings better able to withstand earthquakes than buildings elsewhere. People can live and invest safely in California, knowing that earthquake risk is addressed and that desired levels of seismic safety can be achieved if an effort is made.

Unless seismic safety is afforded a priority that is now lacking, Californians will continue to experience avoidable losses from earthquakes.

Nevertheless, the messages from the Northridge and earlier earthquakes are clear. Despite our codes and world-renowned expertise, too many of our buildings and other structures remain vulnerable to earthquake damage. There are significant weaknesses in the way we exercise land use planning laws and design and construct buildings and lifelines. Too much of what we do is done by people who lack the will, knowledge, or support to deal with a hazard that has the public-safety and economic implications of earthquakes. Much of what we have learned in past earthquakes—and were reminded of by Northridge—is not applied with the appropriate level of commitment, consistency, and priority.

Steps can be taken to reduce future losses to more acceptable levels. California's state and local agencies, building owners, lifelines organizations, construction industry, geologists, architects, and engineers can and must do more to reduce future damage. Earthquake risk will not be reduced significantly until earthquake lessons are consistently applied with a new sense of urgency. The Seismic Safety Commission's recommendations lay out needed actions, but unless seismic safety is afforded a higher priority, Californians will continue to experience avoidable economic and personal losses from earthquakes.

Governor Pete Wilson issued Executive Order W-78-94 after the Northridge earthquake struck the San Fernando Valley and surrounding areas. In that order, he asked the Commission to review the effects of the earthquake and make recommendations on seismic safety and land use planning. The Commission responded by directing the preparation of 39 background reports and relying on research done by others (including members of the Commission), testimonies received at hearings, commissioner-prepared issue statements, and 27 case studies of buildings damaged in the Northridge earthquake.

Effects of the Earthquake

The magnitude 6.7 Northridge earthquake occurred at 4:31 in the morning of January 17, 1994, on a national holiday, when most Californians were at home asleep. Fifty-seven people lost their lives, nearly 9,000 were injured, and damage exceeded $20 billion.

The summary of the Northridge earthquake's impact is "It could have been a lot worse." In fact, it *would* have been a lot worse if the earthquake had occurred later in the day and if its duration and intensity had been of the nature anticipated for most of California. Most of the collapses and other life-threatening failures were to commercial, industrial, and institutional buildings and to freeway bridges, which were virtually empty at the time.

Hundreds of apartment buildings, many of them perched over open parking areas, were damaged; 16 people died in one collapse. Today, concentrations of these buildings are ghost towns, since many owners have not yet been able to rebuild. Thousands of homes and apartments were damaged; though much of the damage was not severe enough to compromise safety, it will cost billions to repair or replace these residences.

Thousands of commercial buildings were damaged. Building codes that were revised for tilt-up concrete buildings after the 1971 San Fernando earthquake need to be further revised, and they need to be better enforced; once again, tilt-ups suffered major damage. The performance of steel moment-frame buildings, thought to be state-of-the-art in earthquake resistance, surprised the engineering community; studies are now underway to determine why failures occurred in connections between beams and columns. Much of the damage to these buildings was hidden under fireproofing and finishes, so previous earthquakes may also have caused undiscovered damage and weakened buildings.

Although fires following earthquakes are significant hazards for California, fires were not a major problem in this event. However, mobile home parks suffered disproportionately when fires fed by natural gas swept through them.

Freeway bridges built or designed before the mid-1970s that had not yet been addressed by Caltrans' retrofitting program suffered major damage and collapse; with a few exceptions, bridges built or retrofitted since then performed well. The cost of repair was over $350 million.

Predictably, telephone systems were compromised, not primarily because of equipment failures but because of system overloads. And as usual, the various emergency response units—firefighters, police, highway patrol, sheriff, medical, and mutual-aid units—and hospitals had difficulty communicating because of incompatible radio equipment, loss of power, inadequate backup power supplies, and damage to equipment.

Other utilities also suffered failures. Electricity was out for up to three days in some areas, but power was restored to most customers within 24 hours. Most of the natural-gas lines that broke were old pipe, which is being replaced as part of a continuing pipeline replacement program. Water lines broke, and water had to be trucked to some of the hardest-hit areas for several weeks.

To these physical damage losses must be added the losses from business interruption, closings of universities and schools, foreclosures, and

reduction of the tax base. Insurance claims reached around $11 billion.

Although many scars remain, and the life losses and some financial losses are permanent, the Los Angeles area as a whole will recover from the Northridge earthquake. The new debts assumed to make repairs will be paid off, the affected businesses will recover, the people will return to their daily rounds. All too quickly, measures to reduce losses from future earthquakes seem less and less important to residents and government officials unless steps are taken to reverse the usual pattern observed after past earthquakes.

Buildings

The Northridge earthquake demonstrated that, although California's current building codes and practices are generally adequate to protect lives, they are not intended to protect Californians from the economic disaster that a major earthquake would cause. California has many of the world's best earthquake safety experts and one of the most comprehensive building codes for earthquake resistance. The low loss of life in the Northridge earthquake compares favorably to similar earthquakes in other parts of the world, but the unprecedented economic losses indicate that California still needs to make major efforts to reduce the earthquake damage vulnerability of its buildings.

The Northridge earthquake exposed a large urban building stock to intense shaking for the first time in California since the advent of modern building codes. Strong shaking lasted only about nine seconds; nevertheless, it vividly demonstrated that, although California has come a long way since the 1971 San Fernando earthquake, there are many improvements that still should be made to ensure that California's economy, as well as its citizens, survive major urban earthquakes:

- *The quality of design and construction must be improved.* Poor quality in design, plan review, inspection, and construction were encountered over and over again in the buildings damaged by the earthquake. California's current system of building design and construction encourages individual gambles that add up to a significant risk, both for those who own the buildings and for those who depend on them as employees, tenants, or customers. Improving the quality of design and construction for new buildings and retrofit projects would increase safety dramatically at relatively minor increases in building costs.
- *Building codes must be improved.* As expected, damage was more prevalent in older buildings. Modern buildings—those built to current codes—in general met the intended life safety objective of the building code. Notable exceptions to this included poor performance in modern concrete parking structures, tilt-up buildings, and welded-steel moment-frame buildings. Code changes have been proposed to begin to address these and other problems for future construction. Future codes and seismic design guidelines should take better account of enhanced performance objectives and geologic and near-source effects on structures. In light of the extensive and costly damage to modern buildings, the state should be more active in its support of efforts to establish acceptable levels of earthquake risk in buildings and to develop codes and design guidelines to meet performance objectives.
- *Nonstructural hazards must be reduced.* A building's heating and air conditioning systems, lighting fixtures, fire sprinklers, furniture, and equipment can become hazards in an earthquake if they are not adequately secured, and their loss can make a building unusable. Making these systems more secure is a relatively inexpensive way of improving seismic safety and post-earthquake functioning of both new and existing buildings.
- *Risks from existing buildings need to be identified, disclosed, and reduced.* Some types of older buildings pose significant threats to both life and economy in earthquakes, but it is impractical to

The Northridge earthquake exposed a large urban building stock to intense shaking for the first time since the advent of modern building codes.

recommend replacement or retrofit of all such buildings overnight. Local governments can reduce the risk through better land use planning and zoning incentives, but financial incentives are needed to encourage owners to retrofit.

California's current system of building design and construction encourages individual gambles that add up to a significant risk.

Some types of buildings demonstrated special problems during the Northridge earthquake. Old, poorly built or maintained single-family dwellings and multistory wood-frame buildings with inadequately braced ("soft") first stories are vulnerable to damage. Many mobile homes were thrown from their supports; some were destroyed by fires fed by sheared natural-gas connections. Despite code changes after the 1971 San Fernando earthquake, tilt-up and masonry buildings and aboveground concrete parking structures sustained significant damage with serious economic implications. Many older concrete-frame buildings are vulnerable to sudden collapse and pose serious threats to life.

Welded-steel moment-frame buildings, once considered to be state-of-the-art in earthquake resistance, suffered serious damage to their connections, damage with serious implications that must be investigated and solved. Public school and modern hospital structures generally performed well, thanks to the extra care taken in their design and construction, but nonstructural damage was serious enough to prevent some from functioning immediately after the earthquake. California State University at Northridge suffered major damage to a parking structure and serious damage to several other buildings, demonstrating the need for better design review and construction inspection.

The earthquake demonstrated that unreinforced masonry buildings that had been retrofitted to preserve life safety withstood the earthquake better than those that were not retrofitted. However, many were still damaged beyond hope of repair, and owners who did not understand the goal of retrofitting were disappointed. Retrofitted older concrete and wood buildings also appear to have performed better than their unretrofitted counterparts.

An overriding question that arises from the Commission's study of the effects of the Northridge earthquake on buildings is "What level of risk to the public is acceptable?" Professionals can describe the risks, but policy makers, owners, and others may not understand the implications and, therefore, not be able to make truly informed decisions about what is acceptable. We could build nothing but square one-story houses with few windows on flat ground well away from any known fault; that would minimize earthquake risk, but would significantly reduce the livability of our homes. Or we could build "disposable" buildings, intended to be replaced after the first damaging earthquake. The answer lies somewhere between these extremes, and the Commission believes the question must be answered at a policy level before building codes and state law can adequately address the practical issues of improving buildings.

Lifelines

All the affected area's lifeline systems—freeways, railroads, and communications as well as natural-gas, water, power, and sewage-disposal systems—suffered damage in the Northridge earthquake. The most spectacular failures, those of the freeway bridges, raise questions regarding design and construction of new bridges as well as retrofitting of existing ones. Although Caltrans is addressing these problems, the Commission believes the toll bridge retrofit program must be accelerated and properly funded.

Power outages and system overloads were the culprits in most communications difficulties. In this earthquake cellular telephones were also overloaded. The cellular system must have an emergency priority system similar to that of land lines. The most serious failures of communications were in medical and emergency services. Many failures of hospital communications systems were caused by damage to unanchored equipment and failure

of emergency power generating equipment, which in turn was a result of a lack of regular testing or, in some cases, because operators were unfamiliar with the equipment.

That few fires caused by natural gas followed this earthquake was due more to favorable weather and good luck than to the strength of the system. The gas companies need to accelerate their replacement of old vulnerable pipe and to address other weaknesses in the system, such as the hazard created when mobile homes fall off their supports and break gas connections.

The Northridge earthquake caused extensive power outages. A few high-voltage transmission towers were damaged when their footings were displaced. This and other areas of damage should be investigated, and the electric utilities should continue their efforts to improve the ability of their facilities to resist earthquake damage.

In addition to disrupting the delivery of water from the Colorado River and northern California, the earthquake caused many local breaks in water distribution lines; some areas were without water for weeks. The potential for massive disruption of water systems poses significant public health hazards as well as inhibiting firefighting ability and disrupting businesses in the affected area. Like other utilities, water districts must strengthen their systems to withstand earthquakes.

Several dams were damaged but none failed, a testimony to the effectiveness of the owners' strengthening efforts and the Department of Water Resources' Division of Safety of Dams. However, damage patterns indicate that in stronger or longer-lasting earthquakes, it will be a different story. Federal dams, which are built to different standards from the state's, and dams for which failures would inundate heavily populated areas should be reevaluated.

Land Use Planning

Community general plans can be used to identify, avoid, or mitigate seismic hazards, and they can also provide information that local officials need to predict earthquake damage patterns and plan for recovery. Zoning can also be used to discourage seismic hazards. Waivers of zoning regulations are one of the options that cities and counties have for encouraging retrofit or demolition of seismically hazardous buildings. State guidelines for environmental impact reports should include instructions for dealing with seismic hazards of development and redevelopment projects.

Most local officials do not have up-to-date geologic information to help them apply land use planning as a tool to reduce their communities' seismic hazards. The California Division of Mines and Geology's Seismic Hazards Mapping Program must provide this information to the majority of urban California within a reasonable time.

Geologic and Geotechnical Lessons

Like the Coalinga and Whittier Narrows earthquakes in the 1980s, the Northridge earthquake—which also occurred on a blind, or buried, fault—proved that buried faults can cause significant damage. Geologists believe that such faults underlie many California urban areas—not only the Los Angeles basin and the San Fernando Valley, but also the Ventura-Santa Barbara region, the Santa Clara-San Jose region, and other areas.

California has a program under the Alquist-Priolo Earthquake Fault Zoning Act to identify faults that break the surface and mitigate their hazards. These efforts should be broadened to identify areas with buried and other active faults that do not meet the law's definitions of an "active" fault.

Shortly after the Northridge earthquake, there was speculation that the high level of damage resulted from unusual vertical accelerations, but the Commission has received no evidence that vertical accelerations were unusual relative to the horizontal accelerations.

The 168 recommendations in this report form a blueprint to reduce earthquake risks.

Though the Northridge earthquake produced the largest set of ground motion records ever obtained from a California earthquake, many of the badly shaken areas were not fully instrumented. Shaking in the near-source area—the area above and near a fault—has unique characteristics that can increase damage. Near-source and geological effects should be considered in the design of important buildings and in land use planning. More instruments are needed, as well as research to determine what implications the generally more severe ground motions near the epicenter of the earthquake might have for structural design.

Local site conditions played an important part in the level of damage. The Seismic Hazards Mapping Program being pursued by the California Division of Mines and Geology must be accelerated to identify site conditions that might create or add to seismic risks, particularly those under urban areas, so that appropriate precautions can be taken, both in buildings and in land use planning, to minimize earthquake damage.

Reducing Earthquake Risk in California

The 168 recommendations in this report form a blueprint to reduce earthquake risks, but will only be effective if they are carried out with the level of effort needed. To begin, government agencies, businesses, and private individuals must be made accountable for managing their earthquake risks to achieve four basic goals:

- *Make seismic safety a priority.* Responsibility for seismic safety actions and programs is diffuse; seldom can one person or one agency be held accountable for reaching seismic safety goals. Seismic safety is usually only a small part of a business' or public agency's activity—and not the part that brings big rewards or promotions if successful. Indeed, it takes a damaging earthquake to prove that risk-reduction efforts were successful. Efforts and laws to carry out seismic safety programs must receive the attention they need to ensure that California's earthquake risk is reduced. The recommendations clarify responsibility and require accountability. Every agency secretary should be made responsible for the efforts of departments, boards, and commissions within their jurisdictions to make seismic safety a priority.
- *Improve the quality of construction.* Improving the quality of construction from top to bottom is a far-reaching goal in terms of number of people affected—owners, architects, engineers, contractors, workers, inspectors, code writers, materials suppliers, researchers, and more. But it is also the most cost-effective way of reducing California's earthquake risk. The many actions that should be taken reflect the complex nature of the problem, but they boil down to one simple fact: buildings that are properly designed and constructed are better able to resist earthquakes.
- *Reduce the risk from seismically vulnerable structures.* California's greatest earthquake risk is from structures that fail in earthquakes. The types that fail are well known, but identifying individual structures that are likely to collapse and strengthening or phasing them out of use is a monumental task that will take decades of efforts. Nevertheless, the risk must be addressed as a priority. State government can help by developing building retrofit guidelines and financial incentives as it has with Proposition 122 local government grants, but local governments must take the lead in developing similar incentives for individual owners.
- *Improve the performance of lifelines.* Caltrans and most utility companies are aware of the seismic risks to their facilities and are working to reduce or eliminate them. Additional resources and actions are needed to strengthen systems and speed earthquake recovery. Vulnerable structures, pipelines, and equipment must be replaced and reliable backup power and communications provided.

Those four goals can be reached by implementing the Commission's recommendations. Seven broad tasks must be completed to achieve those goals:

- *Define acceptable risk.* State laws and policies have attempted to define acceptable earthquake damage levels for schools, hospitals, and emergency services buildings. Similar policies are needed to define what damage is acceptable for the rest of the building stock, or it will be difficult or impossible to define, let alone achieve, goals of reducing structural and nonstructural damage. Performance objectives over and above the basic goal of life safety are needed; they should reflect the importance of the functions and economic roles of many classes of buildings, and building codes should be revised—and, optimally, simplified—to achieve these objectives. A "California Earthquake Risk Colloquium," an ad hoc task force representing the various business, government, emergency management, health and social services, and public safety interests that could contribute should be convened by the Commission and charged with recommending an appropriate state policy on acceptable earthquake risk.
- *Provide incentives for risk reduction.* Interest in improving earthquake risk-reduction efforts—and the willingness to spend money on them—disappears quickly after each damaging earthquake. Permanent financial and other incentives need to be developed that will keep the level of interest high enough to make sure that risk reduction is carried out over the long term. Such risk reduction helps more people than just the building owners; the whole community benefits from a more predictable business climate, quicker earthquake recovery, and enhanced public safety.

  Even if building owners are aware of the seismic hazards of their buildings and want to address them, they are often hard pressed to obtain the resources needed. And it is difficult, whether at the state or local-government level, to provide financial incentives. The private sector can help by adjusting interest rates and insurance premiums and deductibles to reflect seismic risks; government can supply the information needed to develop these tools as well as providing grants, loans, and other incentives for risk reduction.
- *Improve the use of earth science knowledge to reduce risk.* The earth sciences have developed a great deal of information about California geology, but much of it is not in a form that can be used by builders, local government planners, or state lawmakers. Accelerating the progress of the state's Seismic Hazards Mapping Program would go a long way toward filling this gap. Improvements in how Uniform Building Code land-excavation and grading requirements are enforced and in continuing education for earth science professionals are also needed. Building designers must do more to take the effects of geologic conditions and the unique shaking characteristics near faults into account.
- *Improve the use of land use planning to manage seismic risk.* General plans, zoning and subdivision regulations, and environmental reviews can provide powerful tools for reducing and avoiding earthquake risk. Some relatively minor changes to existing laws and practices would make these tools more usable, such as requiring general plans to incorporate a description of the building stock and mitigation measures or incentives to reduce risk from vulnerable buildings.
- *Improve the code development process.* The current method of developing building codes with volunteer efforts has worked well in the past but has resulted in long, complicated regulations that are often slow to recognize new advances. Moreover, no single organization is accountable for substantiating the basis underlying the

code provisions. The California Building Standards Commission should be empowered to make improvements in the codes and in the code development process to make sure that code assumptions are valid and that design guidelines will meet performance objectives. More active state government support for developing building codes will have long-term impacts on the earthquake resistance of California buildings.

- *Support focused research.* The more California learns about earthquake mechanisms and damage, the better prepared we become. However, there are many critical aspects as yet unanswered. Where are the buried faults, and what kinds of earthquakes will they cause? How can damaged steel-frame buildings be repaired, and how can that kind of damage be prevented? What are appropriate guidelines for evaluating seismic performance? What are the true strengths of commonly used building hardware? Without focused research California will continue to invest billions in improvements that are not necessarily reliable during earthquakes. California needs answers to these questions more urgently than any other state. The state should amend existing statutes to create and fund the Center for Earthquake Risk Reduction, an entity to plan for and fund focused research to develop answers to such practical questions so they can be applied to reduce earthquake risks. The center would emphasize measures to ensure that research results are actually put to use by practitioners.
- *Improve state-level programs.* Resources, authority, responsibility—these are the key elements for making state seismic safety activities effective. State agencies that have seismic safety responsibilities must make them an important part of their mission, not just an afterthought; plans and schedules for implementation of these responsibilities should be a part of every budget request. State agencies and California's university systems must forecast the damage and disruption that will be caused by likely earthquake events and plan to reduce these effects.

The Commission believes that its role in carrying out California's earthquake risk-reduction programs should continue to be independent and advisory. Its unique perspective in considering all aspects of earthquake risk reduction, response, and recovery will help it identify those actions most likely to be effective in turning the lessons from earthquake losses to California's gain.

The Northridge earthquake lends new urgency to the need to carry out the initiatives in *California at Risk*, the outline of the California Earthquake Hazard Reduction Program. It is imperative that adequate funding be provided to meet the state's goal of reducing earthquake risk significantly by the end of this century.

Summary of Recommendations

Geologic and Geotechnical Aspects of the Northridge Earthquake

Using Geologic Information

- California Division of Mines and Geology (CDMG) use independent peer review by acknowledged experts representing scientists, hazard analysts, and users throughout the hazard mapping program.
- CDMG draw on resources outside state government to conduct the mapping program.

Strong-Motion Instrumentation

- The state continue its strong support of Strong Motion Instrumentation Program (SMIP) as a valuable part of California's effort to reduce the risk from earthquakes.
- SMIP exert leadership by organizing a workshop involving the other operators of strong-motion instrument networks in California to coordinate the deployment and operation of these networks.
- Public funds not be used for the purchase, deployment, or upgrading of strong-motion instrument networks operated by private organizations unless there is a plan for the maintenance of the instruments and an agreement for the timely release of data to the public.
- SMIP give high priority to establishing a network of reference stations to measure ground motions in major urban areas of California.

Buried Faults

- CDMG identify areas where active buried faults exist that may cause serious damage and loss of life. By December 31, 1995, CDMG should conduct short-term, focused studies including:
  - Mapping of geologic and geomorphic indicators of buried faults (for example, pressure ridges and sag ponds).
  - Compiling subsurface geologic, geophysical, seismological, and geodetic data and analyzing these data and knowledge of active tectonics.
- CDMG form an advisory working group of knowledgeable earth scientists to develop cost-effective methods for assessing the locations as well as the significance of buried faults, the potential for earthquakes of various magnitudes, and motion parameters.

Site Conditions

- Building codes, standards for design and retrofit of lifelines, and land use planning incorporate measures to identify and set priorities to reflect adverse seismic effects of local site conditions.

Ground Deformation

- CDMG, as part of its Seismic Hazards Mapping Act (SHMA) program, evaluate the level of hazard presented by possible subtle faults, buried faults, and incipient faulting in alluvial basins in active tectonic environments and zones of compression.
- CDMG, as part of its SHMA program, and under the policies of the State Mining and Geology Board, expand the categories of seismic hazards to create a new hazard zone to address ground deformation and amplified shaking associated with folding and faulting.

Engineered Fill

- State and local jurisdictions enforce provisions in Appendix Chapter 70 of the 1991 Uniform Building Code (Appendix Chapter 33 of the 1994 UBC) as a minimum code for excavations and fills.
- Fills intended to support structures be designed and inspected by qualified professionals to ensure conformance with the current code and engineering practice; qualified technicians with proper certification inspect construction; the engineer of record certify that fill placement is in

Engineered Fill
(continued)

conformance with plan design; and when the fill is to be placed on bedrock, an engineering geologist inspect the geologic conditions before placement.

- Seismically induced deformation caused by seismic compaction of fill and underlying alluvium be considered in the design and construction of residential fills.

Continuing Education of Geosciences Professionals

- The Department of Consumer Affairs' licensing renewal process require continuing education for geologists, geophysicists, engineering geologists, and geotechnical engineers.
- Licensing boards for geologists, engineers, and architects be required to hold hearings after each earthquake in the affected area to learn how their requirements can be improved.

Achieving Seismic Safety in Buildings

Owners' Responsibilities

- Appropriate state agencies develop a strategy to make owners aware that:
  - They are responsible for seeing that reasonable and appropriate care is taken to hire qualified designers, inspectors, independent reviewers, and contractors and for clearly delineating the lines of responsibility for their functions in appropriate contract documents.
  - The building system with the lowest initial construction cost may actually have a shorter useful life and be significantly less resistant to earthquakes than a slightly more expensive system or a building of higher quality.
  - They are responsible for taking reasonable and appropriate precautions to protect building contents.
- Legislation be enacted to direct California Occupational Safety and Health Administration (CalOSHA) to adopt standards for bracing building contents and to promulgate and enforce regulations to require employers to include this information in their workplace safety and emergency plans.

Designers' Responsibilities

- The California Building Standards Commission (CBSC) change the state's building standards to require that every building project have a single line of responsibility for the entire lateral force resisting system and vertical load carrying system assigned to the engineer or architect of record.
- CBSC amend the California Building Code (CBC) to require designers of record to be responsible for a quality assurance program for structural and nonstructural elements for each project and, through personal knowledge, for the general compliance of construction with the contract documents.
- Legislation be enacted to hold designers harmless from claims, other than those claims specifically involved with observation of the work designed by the designer, when present at construction job sites.
- The Legislature periodically review licensing board activities to ensure that they are administering effective licensing examinations, requiring continuing education to maintain competency, and enforcing registration rules.
- The boards of registration for architects, engineers, and geologists hold hearings at the site of each damaging earthquake to determine the effectiveness of the boards in providing the necessary enforcement to ensure consumer protection and quality control over professional workmanship.
- The Board of Registration for Professional Engineers and Land Surveyors and the Board of Architectural Examiners raise the level of awareness of board rules that limit professional practice to areas of competency and the level of enforcement of those rules.

Designers' Responsibilities (continued)

- Legislation be enacted to amend the title act for structural engineering to define the minimum level of seismic design expertise required of title holders.

Contractors' Responsibilities

- Legislation be enacted to require the Contractor's State Licensing Board (CSLB) to test candidates for a working knowledge of practical seismic safety principles in their contracting disciplines as part of the normal examination process and to require continuing education to ensure that contractors maintain competency in this area.
- The CSLB hold hearings at the site of each damaging earthquake to determine the effectiveness of the board's efforts to ensure consumer protection and quality control.

Building Code Enforcement Agencies' Responsibilities

- Legislation be enacted to make structural plan checking of engineered buildings an act requiring professional licensing.
- CBSC amend the CBC to require all building code enforcement agencies to require owners of important, irregular, complex, or special-occupancy buildings to hire, as part of the permit process, independent peer reviewers whose involvement starts with schematic design phases and continues through construction.
- Legislation be enacted to require building inspectors and public and private plan checkers to be trained and certified by nationally recognized organizations and subject to continuing education requirements by recognized organizations in their areas of competence. Inspectors and plan checkers should be restricted from inspecting and checking plans beyond their areas of certification and competency.
- CBSC amplify what is already allowed by state law and amend the CBC to empower building departments to reject incomplete plans and collect additional fees for reconsideration of incomplete plans. Building code enforcement agencies should file complaints against designers and contractors who violate the building code or approved construction documents, and such complaints should receive priority over other complaints.
- CBSC—with the assistance of boards of professional registration, CSLB, and inspection and plan check certification organizations—develop a standard method for filing complaints on repeat code violators and preparers of incomplete plans.
- Building code enforcement officials and professional associations work together to develop timely changes to the UBC and California amendments to the code to incorporate the changes recommended above.
- Legislation be enacted to require all state, local, and special agencies, including University of California (UC) and California State University (CSU), to have a formal and independent building code enforcement entity with clear and appropriate enforcement, citation, and stop-work responsibilities and authority.

Improving Accountability in the Code Development Process

- Legislation be enacted to designate CBSC as the entity responsible for the adequacy of the seismic safety codes and standards for all buildings in California. CBSC should ensure that building codes and their administration meet the state's acceptable levels of seismic risk through various actions, including but not limited to:
  - Ensuring the adequacy of existing and future seismic safety requirements in the model codes and state amendments.
  - Developing and adopting new seismic safety requirements for amendments to the building code for statewide applications.
- Legislation be enacted to authorize CBSC to establish a task force including other affected and interested agencies and organizations to develop plans to fulfill this responsibility within one year of the above legislation.

Acceptable Seismic Risk

- The Governor support and participate in a special high-level task force, the "California Earthquake Risk Colloquium," a meeting convened by the Commission to recommend acceptable levels of earthquake risk and performance objectives consistent with those levels.

Testing and Research

- Legislation be enacted to authorize funds for a Center for Earthquake Risk Reduction with a sustained funding source to help achieve desired earthquake performance for new and existing buildings.

Need for Response Data

- The California Strong Motion Instrumentation Program (SMIP) develop a program to encourage all municipalities in Seismic Zone 4 to designate significant buildings in their jurisdictions and to adopt building instrumentation ordinances that require owners of these buildings to install and maintain at least three strong-motion instruments in each.
- SMIP develop and adopt standards for the installation and maintenance of building strong-motion instrumentation and provide for processing, archiving, and disseminating records obtained from buildings instrumented according to these standards.

Reducing Nonstructural Hazards

- The Division of the State Architect (DSA) draft nonstructural seismic standards for new construction and retrofits and submit them to the CBSC to be made mandatory by reference in the CBC.
- CBSC amend the CBC to require a quality assurance plan for all engineered buildings for the design and installation of nonstructural bracing.
- CBSC amend the CBC to require the design professional of record to delegate design, coordination, and field review responsibilities for nonstructural building components.
- The Public Utilities Commission (PUC) work with utilities to develop a program to allow gas utilities to include checks for water heater braces in their routine service calls, to notify building owners if water heaters are not properly braced or equipped with flexible gas lines, and to encourage or require retrofits of water heaters within a reasonable period of time.

Making Existing Buildings Safer

- Legislation be enacted to require that, by the year 2000, local general plan safety elements contain a generalized description of all typical building types and vintages in the community's neighborhoods, with a special emphasis on those vulnerable to collapse from seismic hazards, and a plan to mitigate the risk from these structures.
- Legislation be enacted to require state and local building code enforcement agencies to identify potentially hazardous buildings and to adopt mandatory mitigation programs by the year 2000 that will significantly reduce unacceptable hazards in buildings by the target year of 2020.
- The Seismic Safety Commission, in conjunction with the California Office of Planning and Research (COPR) and other interested organizations and agencies, develop guidelines for state and local governments to use to identify potentially hazardous buildings, amend safety elements, and prepare mitigation plans.

Effects of the URM Law

- The Legislature revisit the state's 1986 Unreinforced Masonry (URM) Law and consider appropriate actions to address the inequities and the public's continuing exposure to risk that have resulted from the failure of a significant number of local governments to comply with the intent of the law so that approximately half of the state's URM buildings remain unstrengthened.

Other Types of Retrofitted Buildings

- Legislation be enacted to require owners of potentially hazardous buildings to disclose seismic risk to potential buyers at the time of sale, to lenders, and to tenants on entering into or renewing leases, or when they relocate within a building.
- Legislation be enacted to allow the warning placards required by existing law to be removed from potentially hazardous buildings that have been retrofitted in substantial compliance with the Uniform Code for Building Conservation, Appendix Chapter 1, provided that the disclosures in the preceding recommendation take place.
- Legislation be enacted to require owners and business operators to include warning placards at the entrances to hazardous buildings of all types, as well as seismic risk management and response plans as part of in their overall emergency plans for safety in the workplace.
- The Governor direct CalOSHA to inspect, cite, and fine employers and operators when these earthquake warning placards and plans are not present during inspections of workplaces.

Single-Family Dwellings

- CBSC amend the administrative portions of the codes to require persons drawing plans for conventional light-frame construction to clearly identify on the building's plans all braced wall lines, wall panels, and their connections.
- Plan checkers be required to indicate that the braced wall lines and panels meet the requirements of the code, and construction inspectors be required to conduct an inspection to ensure that seismic elements are constructed in accordance with the plans and the building code.
- Inspectors receive special training, continuing education, and certification in the basic concepts of structural design in lowrise buildings, the identification and importance of key seismic elements, and the proper installation of materials, hardware, and devices used to provide seismic resistance.
- Banks and insurance companies create incentives to encourage seismic retrofit by offering lower rates on homes that have been retrofitted.

Other Wood-Frame Buildings

- CBSC amend the administrative portions of the codes in California to require professionals who are drawing plans for engineered portions of buildings to include and clearly identify on design plans all vertical and horizontal elements of lateral force resisting systems and their connections.
- Local governments initiate efforts to reduce the seismic risk in vulnerable wood-frame buildings such as collapse-risk apartment buildings with "soft" stories.

Manufactured Housing

- Legislation be enacted to require the installation of Housing and Community Development (HCD)-approved earthquake resistant bracing systems or other systems allowed by SB 750 (Roberti) on existing mobile homes when ownerships are changed or when homes are relocated.

Tilt-up and Reinforced Masonry Buildings

- The International Conference of Building Officials (ICBO) Evaluation Service review the building product evaluation and approval procedures used to establish allowable design values for earthquake resistance.

Concrete-Frame Buildings

- The state continue its support of the Seismic Retrofit Practices Improvement Program but recognize that the pace of this program is slow and is just a small step toward addressing the substantial risk posed by concrete-frame buildings.

Steel-Frame Buildings

- The state marshal its academic, technological, government, and industry resources to support the SAC Joint Venture to determine how to repair the steel moment-resisting frame connections damaged in the Northridge earthquake.

Hospitals

- Recently enacted legislation requiring the strengthening of nonstructural systems necessary for essential post-earthquake functions be carried out.
- The Office of Statewide Health Planning and Development (OSHPD), in consultation with the Hospital Building Safety Board, assign the highest priority to quickly retrofitting building components that have proven to be particularly vulnerable and disruptive—sprinkler and other water lines, emergency power, large oxygen tanks, and telephone and radio communications—before requiring retrofits for all the less critical nonstructural items in hospitals.
- OSHPD develop and adopt complete administrative regulations for hospitals, skilled nursing facilities, and intermediate-care facilities and develop and adopt regulations to allow OSHPD to issue minor citations or stop-work orders when violations are observed on construction projects under its jurisdiction.
- Legislation be enacted to require at least one go-slow elevator in each wing of all OSHPD-approved multistory healthcare facilities. This legislation should include the retrofitting of one elevator in all existing multistory healthcare facilities.
- Legislation be enacted to require hospitals to install, maintain, and periodically test in realistic exercises redundant emergency communications systems that do not rely on land lines. These systems must connect with emergency responders—police, fire, paramedics, and ambulances—and work within the hospital facility.
- The Department of Health Services (DHS) develop regulations in cooperation with Joint Council on Accreditation of Healthcare Organizations and OSHPD for recently enacted legislation to mandate that hospitals develop earthquake disaster plans that account for rapid execution of post-earthquake safety evaluations, realistic scenarios of the post-earthquake conditions of their specific buildings, and the availability and reliability of water, power, communication, and other lifeline services.
- OSHPD develop emergency regulations to establish and clarify its authority to post acute-care facilities after disasters and to prohibit the continued use of severely damaged facilities for acute-care purposes.

Essential Services Buildings

- Legislation be enacted to require state and local agencies to review all pre-1986 essential services facilities for their ability to function after earthquakes and that those found deficient be retrofitted.
- Owners and operators of essential services facilities evaluate and make their emergency communication systems, including their power supplies, earthquake-resistant so that they are not lost during periods of most critical need following earthquakes.
- All new and existing multistory buildings with essential services facilities in upper floors be retrofitted or equipped with at least one go-slow elevator.
- A general obligation bond measure be placed on the 1996 ballot to fund a state and local matching grant program or other funding mechanisms to carry out the recommendations in this section.
- The Essential Services Act (ESA) be amended to require buildings designated as community shelters and those buildings that serve as the place of business for local governments, such as city halls, be placed within the definition of “essential services buildings.”

K-14 Schools

- Legislation be enacted to amend the Field Act to require DSA to prepare guidelines and procedures for identifying public-school and community college buildings that have potential collapse risks and to require public-school and community college districts to evaluate the seismic vulnerability of buildings and school structures built prior to 1976, correct all defects resulting from design, construction, deferred maintenance, or inflexible utility connections during repairs, alterations or additions and retrofit, replace, or phase out of use structures that pose significant risks to life.
- Legislation be enacted to amend the Field Act to authorize DSA to issue minor citations or stop-work orders when violations are observed on public-school construction projects.
- Legislation be enacted to direct DSA and the California Department of Education to determine whether contract bid evaluations and management of school building construction projects are typically executed by properly trained, licensed (where necessary), and qualified personnel within school districts and determine whether the state needs to establish minimum guidelines and personnel qualifications.
- Legislation be enacted to consider the appropriateness and feasibility of requiring prequalification of potential contractors before the submission of bids.

Portable Classroom Buildings

- Legislation be enacted to require public school districts and community colleges to attach portable classrooms to foundations and abate life-threatening nonstructural hazards as proposed by DSA.
- The DSA Field Act Advisory Board work with DSA to develop appropriate legislative language and implementing regulations.

Covered Walkways, Lunch Shelters, and Canopies

- The Legislature develop an adequate funding source for addressing deferred maintenance in public schools.
- Legislation be enacted to direct public schools to review walkways, shelters, and canopies to identify and retrofit those that might endanger students during earthquakes.

Nonstructural and Building Contents Hazards

- All public-school and community college districts evaluate nonstructural elements and abate unacceptable hazards. The Field Act should be amended to require DSA to adopt retroactive, mandatory retrofit standards regarding nonstructural hazards. Public-school and community college districts should be required to abate nonstructural and building contents hazards when undertaking major alterations, additions, renovations, or repairs. In any event, retrofits should be completed no later than 2010.
- A percentage of future school bond proceeds be used to abate life-threatening nonstructural and building contents deficiencies in public schools by 2010.
- Legislation be enacted to require personnel at every school district facilities office to be trained to recognize nonstructural hazards and the effective installation of restraints and anchorages and to require an annual refresher briefing on emergency plans for every administrator and teacher.

Private Schools

- Legislation be enacted requiring that at the time of sale or renewal of leases, private-school and preschool building housing 25 or more students and constructed before 1986 be evaluated by a structural engineer and that life-threatening earthquake risks, both structural and nonstructural, be mitigated.
- Legislation be enacted to require private schools to identify and abate nonstructural and building contents hazards in buildings housing students and in classrooms.

School Emergency Plans

- Legislation be enacted to clarify that laws requiring school emergency plans are mandatory and that public-school administrators, boards, and private schools are accountable for compliance.
- Legislation be enacted to direct the California Department of Education to provide up-to-date guidelines specifying the minimal requirements for these plans, including equipment, tools, supplies, and frequency of exercises.

Higher Education Facilities

- The Governor direct the University of California (UC) and California State University (CSU) to require each campus facilities manager to determine key buildings and academic functions needed to restore key educational and research programs after earthquakes in addition to life safety concerns that must continue to be the first priority of campus retrofit programs. Earthquake response plans should be established to redirect or restore such critical academic and research functions in a timely manner for realistic earthquake scenarios. The UC and CSU systems must review the pacing and priorities of their seismic retrofit programs, including nonstructural risk-reduction efforts, to ensure that they will be capable of resuming critical educational and research programs after major earthquakes in a timely manner.
- The Governor direct UC and CSU to establish the goal that all life-threatening structural and nonstructural seismic hazards in UC and CSU buildings be retrofitted by the year 2005.
- UC and CSU prepare a capital budget plan that would allow completion of seismic retrofitting of all university buildings that pose unacceptably high seismic life safety risks by the year 2005.
- Legislation be enacted to require UC and CSU to adopt guidelines that trigger the seismic retrofit of all hazardous, life-threatening university buildings upon major alterations, reoccupancies, additions, renovations, or repairs.
- DSA complete its effort to develop building seismic retrofit guidelines in cooperation and concurrence with UC, CSU, and other interested organizations by May 1995.
- The Governor direct the UC Board of Regents and the Legislature enact new laws to ensure that UC and CSU abide by the minimum seismic design standards and enforcement practices of Title 24, including independent peer review, thorough plan checking, field inspection, and the monitoring of construction by designers for all new, remodel, and retrofit projects.
- The university systems adopt stop-work and citation authority for their code enforcement personnel to reduce minor violations of and enhance compliance with Title 24.
- The Legislature provide sufficient funds for the seismic retrofit of UC and CSU buildings by the year 2005.
- Legislation be enacted to approve the use of program-based budgeting for state seismic retrofit programs as opposed to the current project-phased budgeting that requires delays and added costs due to multiple legislative approvals of each project.

Achieving Seismic Safety in Lifelines

Pace of Caltrans Retrofit Programs

- The toll bridge retrofit program be accelerated because of the critical importance of those structures and that Caltrans' efforts to do so be supported.

Steel or Concrete Girders

- Caltrans perform seismic performance probabilistic risk assessments of both concrete and steel designs as part of its continuing program of evaluation and improving the seismic safety of bridges.

New Technologies

- Caltrans study different types of seismic isolation and damping systems to protect bridge girders and columns from earthquake damage and take into consideration the effects of local soil conditions and near-source ground motion.

Use of Seismic (Base) Isolation

- Caltrans undertake a study of the effects of near-source motion on seismic-isolated bridges before building or retrofitting any seismic-isolated bridges.

Strong-Motion Instrumentation

- The bridge instrumentation program be expanded to install strong-motion instruments, including dynamic strain gauges and load cells on selected strategic bridges.
- Caltrans continue to tie seismic research funding to its capital outlay program rather than the Transportation Planning and Research Act.

Multimodal Transportation Systems

- Multimodal transportation and emergency rerouting issues be considered by Caltrans in all seismic design, planning, and policy decisions.

Railroads

- The PUC review the earthquake response and risk-reduction programs of California's railroads and adopt regulations, including deadlines, for such programs by December 31, 1995.

Natural-Gas Transmission and Distribution Lines

- California utilities accelerate their upgrade and replacement programs to improve the performance of seismically vulnerable gas transmission and distribution lines. Priority should be given to those pipelines in the vicinity of essential facilities, special occupancies, and dense population, and in areas of potential ground deformation.
- Emergency response procedures be improved and valves installed in areas where ruptures are more likely so that breaks can be rapidly detected and lines depressurized to reduce the potential for explosions or gas-fed fires.
- The PUC issue recommendations and regulations to ensure improvement in the safety and seismic performance of gas transmission and distribution lines, including implementation schedules and priorities and the use of automatic shut-off valves, as appropriate, by June 30, 1996.

Mobile Home Gas Service

- Automatic gas shut-off valves be mandatory at the service entry point at all mobile home parks in California.
- The PUC conduct hearings and workshops to determine the best method for providing shut-off valves for mobile home parks and appropriate performance standards for such valves and to prepare draft legislation mandating shut-off valves for mobile home parks by September 1, 1995.
- The Department of Housing and Community Development develop and institute an education program for mobile home owners and park managers to encourage and guide installation of seismic bracing for mobile homes, proper bracing for water heaters in mobile homes, and measures to reduce the risk of gas-fed fires in mobile homes and mobile home parks.

Residential Gas Service

- The PUC sponsor a task force of representatives from the California Utilities Emergency Association (a division of the Office of Emergency Services), utilities, construction, manufacturing, emergency and fire services, and local governments to evaluate the damage data from the Northridge earthquake and other recent earthquakes, define the risks of fire and potential for damage and injury, and review alternative mitigation methods, including the use of earthquake-activated shut-off valves.
- DSA review the adequacy of its criteria for earthquake-activated gas shut-off valves and revise them to improve reliability.
- The PUC use the task force results to adopt requirements by June 30, 1996, to reduce natural-gas earthquake risks to an acceptable level and recommend actions for utilities outside the PUC jurisdiction.

Electric Utilities

- Measures be taken by investor-owned and municipal utilities to improve the performance of substations and transmission lines.
- The PUC investigate and evaluate the causes of substation equipment damage and transmission tower failures; the actions utilities are taking to identify the potential for similar failures and improve substation equipment and transmission tower performance; the use of site-specific geologic and geotechnical information for locating and designing utility facilities; and the adequacy of current utility risk-mitigation programs.
- The PUC determine whether mandatory regulations are required for design and location of substation equipment and transmission towers to ensure adequate component and system performance. If regulations are deemed necessary, the PUC should issue such regulations by July 1, 1996.
- Electric utilities not under the jurisdiction of the PUC, such as municipal utilities, cooperate with the PUC and other utilities in reviewing their seismic mitigation programs and the governing boards of those utilities adopt regulations and practices at least as stringent as those mandated by the PUC for private utilities.

Emergency Power

- Legislation be enacted to require those who own essential communications and emergency services facilities or hospitals to provide for reliable backup power in conjunction with utilities.
- The Air Resources Board investigate claims that local air quality maintenance district restrictions prevent regular testing of emergency generators and resolve any conflicts to allow testing.

Water Supply

- The Department of Water Resources issue a report to all water utilities describing the reasons behind the failures of large-diameter piping, distribution piping, water tanks, and other system components and providing representative risk-mitigation programs to identify and address seismic vulnerabilities.
- Legislation be enacted to require each water utility within California to prepare a seismic mitigation program consisting of a seismic policy and a statement of acceptable levels of risk; a description of potential earthquake damage and system impacts based on likely earthquake scenarios; a priority-based long-term risk-mitigation program; and a commitment to fund the program.

Communications

- The owners of essential services facilities ensure the adequacy of backup power generation systems and assess whether these systems can resist earthquakes.
- The agencies that rely on communication systems during emergency response have reliable redundant backup systems.
- The Office of Emergency Services (OES) explore the possibility of identifying and licensing additional mutual-aid channels in both the VHF and UHF bands for police and fire service use statewide.
- OES continue to place high priority on working with the Federal Communications Commission (FCC) to address standards for radio equipment that will enhance direct communications between police and fire agencies, including those assigned through mutual aid.
- The PUC work with the cellular industry to facilitate limiting access to cellular phones to essential services after declared disasters.
- The Emergency Medical Services Authority investigate problems with emergency medical communication systems and specify measures to correct inadequacies, including requiring testing of emergency communication systems and training personnel.
- The ESA be amended to require that switch facilities for land lines and cellular communications be located only in buildings constructed or retrofitted to seismic requirements at least as stringent as those found under the Essential Services Buildings Act.

Communications (continued)

- The Governor petition the FCC to:
  - Provide additional frequency spectra for public safety services and expedite the development of appropriate standards and protocols to facilitate direct communications between systems.
  - Limit access to cellular phone service to essential services after a declared disaster.

Dams

- The owners of dams be required to fund a dam instrumentation program carried out by the Strong Motion Instrumentation Program at the direction of the Division of Safety of Dams (DSOD).
- DSOD review its current assessment procedures in light of the strong-motion data obtained from the Northridge, Loma Prieta, and Landers earthquakes and assess concrete dams in areas having a likelihood of intense shaking and where the release of water would have significant public safety consequences.
- DSOD be directed to conduct seismic reevaluations and to increase inspection frequency of high-risk dams in zones of high seismic hazard.
- Legislation be enacted to allow DSOD to establish a research program directed towards improving and verifying methods of analyzing the seismic performance of dams.
- The Governor petition the federal government to ensure that all federal dams in California are designed, built, inspected, and repaired to state requirements.

Achieving Seismic Safety Through Land Use Planning

General Plans and Safety Elements

- CDMG complete the Seismic Hazards Mapping Act program by 2005.
- Legislation be enacted requiring review of the safety element of general plans every five years to incorporate new information; the information in maps prepared under the SHMA should be incorporated within one year of the date final maps are provided to local jurisdictions.
- Legislation be enacted to make the existing optional CDMG review of safety elements mandatory for CDMG.
- Legislation be enacted to require that the safety elements of general plans address seismic vulnerability of existing building stock, or inventory, and contain risk-mitigation strategies. Description of the building stock should be included in enough detail to support the risk-mitigation strategy.
- Legislation be enacted to require CDMG to convene a high-level independent review board for the preparation and review of guidelines and maps prepared under the SHMA.
- CDMG work with local governments to establish a systematic program to ensure that the information provided by the SHMA program can be easily incorporated into general plans and zoning, subdivision, and environmental quality decisions.
- CDMG work with the Insurance Commissioner and representatives of the insurance industry to ensure that mapped hazard areas are not misinterpreted and used incorrectly in issuing insurance policies.
- CDMG and OES support the preparation of damage scenarios, including localized scenarios and scenarios for areas of the state not presently covered.

Zoning, Subdivision, and Environmental Reviews

- State California Environmental Quality Act guidelines be amended to require that EIRs address seismic hazards, and engineering geologists and civil engineers, practicing within their areas of competence, review the hazards and proposed mitigation measures.
- Legislation be enacted to amend the Subdivision Map Act to require that geologic and geotechnical reports addressing seismic hazards be required for all major (five lots or more) subdivisions unless information is already available or until superseded by SHMA maps and that reports be reviewed by local government staffs or consultants with appropriate credentials.

Alquist-Priolo Earthquake Fault Zoning Act

- Legislation be enacted to allow designation of active fault zones based on all viable geologic, geodetic, and tectonic evidence and provide for alternative mitigation measures to be defined by the Mining and Geology Board as appropriate to complex areas where the location of potential fault ruptures is uncertain.
- Legislation be enacted to apply the Alquist-Priolo Act to publicly owned facilities, critical facilities, and lifelines, including public utility pipelines and facilities in which hazardous materials are used or stored, and to provide for alternative mitigation measures appropriate to lifelines.

Inundation Mapping

- Legislation be enacted to impose sanctions on dam owners who fail to prepare and submit inundation maps by December 31, 1996.
- Legislation be enacted to require that inundation maps be reviewed and revised whenever downstream development could significantly change hydrologic patterns and to require that inundation maps be reviewed every ten years and revised when necessary to reflect new data and to incorporate new inundation mapping technology.
- Legislation be enacted to amend land use laws to require state and local agencies to make specific findings regarding the acceptability of inundation hazards before approving development of critical facilities (for example, hospitals, schools, emergency response facilities, hazardous material storage, and sewer treatment plants) within potential inundation areas.
- The Governor petition federal agencies responsible for dams in California to provide inundation maps for their facilities to the state and local agencies.
- Legislation be enacted to require owners to prepare inundation maps for low-lying areas protected from flooding by levees.

Hazardous Materials

- State general plan guidelines be revised to require safety elements to include maps that depict where acutely hazardous materials are stored, used, and transported and their relationship to seismic hazards and that circulation elements address the existing and proposed location of pipelines transporting hazardous materials.
- Legislation be enacted to amend the Alquist-Priolo Act and the SHMA so they apply to all facilities that produce or store reportable quantities of acutely hazardous materials.

Historic Buildings

- The State Historical Building Safety Board revise the State Historic Building Code to include minimum life safety standards and guidance on measures to control damage.
- The California Office of Planning and Research (COPR), in consultation with the Office of Historic Preservation, publish guidelines for adding optional historical resources elements to local general plans to address the seismic retrofit of historic buildings.

Redevelopment

- Legislation be enacted to allow redevelopment agencies to increase spending caps easily after a natural disaster to accommodate disaster-recovery activities, including repairs to appropriate standards.
- Legislation be enacted to add to the definition of “blight,” when designating a redevelopment project area, those structures deemed by the local jurisdiction to pose an unacceptable risk of collapse in earthquakes.

Planning for Recovery

- The CBSC amend the CBC to include triggers to require that alterations, repair, retrofit, and reconstruction activities incorporate seismic upgrades to mitigate future earthquake damage. The code should allow setting aside mandated upgrades not related to life safety that may be triggered when elective remodeling projects are undertaken.
- Legislation be enacted to require local general plans and emergency plans to address post-earthquake recovery and rebuilding.

Training

- The American Planning Association, the League of California Cities, and the County Supervisors Association of California institute formal training on earthquake principles for their members.

Reducing Earthquake Risk in California

Most of the recommendations in this section are summaries of previous ones.

Making Seismic Safety a Priority

- The Governor direct agency secretaries to be responsible for the progress of every department, board, and commission under their jurisdiction in carrying out their seismic safety responsibilities.

Improving the Quality of Construction

- The Governor direct that California's codes and regulations be amended to:
  - Require that a single design professional be responsible for the complete seismic design of each engineered building, indicate earthquake bracing elements and connections on plans, specify quality assurance plans, and observe construction of critical elements.
  - Improve the way licensing boards test engineers, architects, and geologists on seismic principles and aggressively enforce licensing board rules regarding professional competence in seismic safety matters.
  - Require plan checkers to review the lateral force resisting elements and inspectors to inspect these elements thoroughly, require independent peer review of important or complex buildings and authorize state and local government building departments to reject incomplete or incompetent plans, collect additional fees when the poor quality of design creates additional review work, and file complaints with licensing boards.
- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend the practice acts for professional engineers and architects to require continuing education and the title act for structural engineers to define the level of seismic expertise necessary to attain and keep the license and to require structural plan checking of engineered buildings by licensed professional engineers or architects.
  - Require testing of contractor license candidates on basic seismic safety principles in construction and continuing education of licensees.
  - Require building inspectors and plan checkers to be trained and certified under programs provided by recognized organizations.

Reducing the Risk from Seismically Vulnerable Structures

- The Governor require state agencies to carry out the recommendations in the report *Policy on Acceptable Levels of Earthquake Risk in State Buildings* (Seismic Safety Commission report SSC 91-01).
- The Governor require the University of California (UC) and the California State University (CSU) systems to prepare capital budget plans for seismic retrofitting of all university buildings that pose unacceptably high risks to life by the year 2005, to determine whether they have the ability to restore critical educational and research programs following damaging earthquakes, and to begin addressing this concern in retrofit programs.
- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend planning laws to require general plan safety elements to include a generalized description of seismically vulnerable building types by neighborhood and a plan to mitigate the risk from these buildings.
  - Enact legislation to require state and local building code enforcement agencies to identify potentially hazardous buildings and to adopt mandatory mitigation programs by the year 2000 that will significantly reduce hazardous and unsafe buildings by the target year of 2020.

Reducing the Risk from Seismically Vulnerable Structures (continued)

- Require public-school and community college districts to evaluate the seismic vulnerability of school structures built before 1976 and retrofit structures with significant life safety risks and to evaluate and abate life-threatening nonstructural hazards.
- Require a portion of future school bond proceeds be used to abate life-threatening structural, nonstructural, and building contents seismic deficiencies.
- Require that private-school buildings, including preschool buildings housing more than 25 students be evaluated for structural, nonstructural, and building contents seismic hazards upon sale or lease renewal, and that life-threatening risks be mitigated.
- Require the UC and CSU systems to adopt guidelines that require seismic retrofit as a condition of carrying out major renovations, reoccupancies, additions, and repairs.
- Place a general obligation bond measure on the 1996 ballot to fund the retrofit of seismically vulnerable state-owned buildings and local government essential services buildings.

Improving the Performance of Lifelines

- The Governor direct Caltrans to revise its retrofit priorities to give more weight to the importance of structures, accelerate the toll bridge retrofit program, meet its stated project completion goals for retrofitting vulnerable structures, undertake a study of the effects of near-source ground motion on seismically isolated bridges, and continue support for research and instrumentation of bridges.
- The Governor direct the Public Utilities Commission (PUC) to take an active role in the seismic safety efforts of the utilities within its regulatory responsibilities. Specifically, the PUC should review the earthquake response and risk-reduction efforts of California's railroads and electric and gas utilities, adopt needed regulations, and draft legislation that will require an earthquake-activated natural-gas shut-off valve at each mobile home park.
- The Governor direct the Department of Water Resources to help water districts identify and address seismic vulnerabilities by disseminating a summary of the causes of earthquake failures in piping systems, tanks, and other system components, and a model risk-mitigation program.
- The Governor direct the Division of the Safety of Dams to review its current assessment procedures in light of data obtained from the Northridge earthquake and to conduct seismic reevaluations and increase inspection frequency of high-risk dams in zones of high seismic hazard.
- The Governor support legislation during the 1995 session of the Legislature to:
  - Require owners of essential communications and other essential facilities and hospitals to provide reliable backup power.
  - Require water utilities to adopt and carry out long-term seismic risk-mitigation efforts.
  - Require dam owners to place earthquake motion recording instruments on major dams.

Defining Acceptable Risk

- The Governor direct the Department of Finance and the California Office of Planning and Research and request the Joint Budget Committee to convene a panel of economists and other experts to estimate the economic impacts of likely earthquake events.
- The Governor support and participate in a special high-level task force meeting, the "California Earthquake Risk Colloquium," a meeting convened by the Commission to recommend acceptable levels of risk and performance objectives consistent with those levels.
- The Governor direct the California Building Standards Commission (CBSC) to work with representatives of the engineering professions, building code groups, building inspectors, and the building industry to implement the performance objectives once they are defined.

Providing Incentives for Risk Reduction

- The Governor convene an ad hoc task force of the agencies and people who can provide incentives to encourage earthquake risk-reduction efforts.

Providing Incentives for Risk Reduction (continued)

- The Governor support legislation to carry out the recommendations for incentives developed by the "Colloquium" during the 1996 session of the Legislature.

Improving the Use of Earth Science Knowledge to Reduce Risk

- The Governor direct the California Division of Mines and Geology to map areas where active buried faults exist, describe the level of hazard associated with these faults and other subtle faults, complete the Seismic Hazards Mapping Act (SHMA) by the year 2005, and use independent peer review to ensure consistency in all aspects of the SHMA program.
- The Governor support legislation during the 1995 session of the Legislature to:
  - Require that state and local jurisdictions enforce as a minimum the Uniform Building Code grading provisions, that fills be designed by qualified professionals considering seismic forces, and that fills be inspected by qualified professionals.
  - Require continuing education for geologists, geophysicists, engineering geologists, and geotechnical engineers as part of the professional license renewal process.

Improving the Use of Land Use Planning to Reduce Seismic Risk

- The Governor direct the California Office of Planning and Research to revise the State Planning Guidelines to address acutely hazardous materials and their relation to seismic hazards.
- The Governor direct the Resources Agency to amend the California Environmental Quality Act guidelines to improve the review of seismic hazards and risk-mitigation measures.
- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend general plan laws to require that safety elements address the seismic vulnerability of the building stock, that elements be updated every five years, that they incorporate information published under the SHMA, and that the existing optional review of draft safety elements by the California Division of Mines and Geology be mandatory.
  - Amend the Alquist-Priolo Act and SHMA to allow designation of faults as active based on geologic, geodetic, and tectonic evidence: to apply the acts to all publicly owned buildings, other facilities, and lifelines; and provide for alternative mitigation measures for buildings in areas of complex faulting and for lifelines.
  - Amend the dam inundation mapping program to impose sanctions on dam owners who fail to prepare and submit maps by December 31, 1996, and to require updating of maps when downstream conditions change and review of maps every ten years.

Improving the Building Code Development Process

- The Governor support legislation during the 1995 session of the Legislature to designate the CBSC as the entity responsible to ensure that building codes and their administrative provisions meet the state's acceptable levels of seismic risk, ensure the adequacy of seismic safety requirements in the codes, and develop and adopt amendments for statewide application.

Supporting Focused Research

- Legislation be enacted to create and fund a state-level Center for Earthquake Risk Reduction to implement a seismic safety research program.

Improving State Seismic Programs

- The Governor direct each state agency with the authority to design, construct, and lease facilities and those with responsibility for seismic safety programs, to:
  - Report to him on how seismic safety will be afforded priority attention.
  - Incorporate ongoing independent peer review on all seismic matters, including planning and priorities.

EXECUTIVE DEPARTMENT
STATE OF CALIFORNIA

Executive Order W-78-94

WHEREAS, I, PETE WILSON, Governor of the State of California, having declared a State of Emergency based on conditions of extreme peril to the safety of persons and property within the Counties of Los Angeles, Orange and Ventura, State of California, beginning on January 17, 1994; and

WHEREAS, building design and construction standards in California have consistently lead the world in seismic safety; and

WHEREAS, the January 17, 1994, Northridge earthquake was the first major earthquake in California to occur directly beneath a highly urbanized area; and

WHEREAS, the performance of buildings in events such as the Northridge earthquake need to be better understood; and

WHEREAS, these considerations have important implications for building design standards, and other seismic safety policy; and

WHEREAS, the public should benefit from the broad range of seismic knowledge and experience present within the Seismic Safety Commission, and throughout private industry and public institutions; and

WHEREAS, strict compliance with all statutes, rules and regulations prescribing procedures for the conduct of certain state business, specifically the award and administration of state contracts would hinder and delay the completion of this important study;

NOW, THEREFORE, I, PETE WILSON, Governor of the State of California, do hereby direct the California Seismic Safety Commission to review the effects of the Northridge earthquake and to coordinate a study of the specific policy implications arising from the Northridge earthquake, with particular attention to implications for seismic structural safety, and land-use planning:

IT IS FURTHER ORDERED that the Commission, in its work to examine the need for changes in seismic building standards, avail itself of the expertise available from building design and construction professionals; as well as academia, by creating a process for the inclusion of the following organizations in this study: the Associated General Contractors of California, the American Institute of Architects, California Chapter; California Building Industry Association, Consulting Engineers & Land Surveyors of California, Structural Engineers Association of California, Earthquake Engineering Research Institute, the Mayor of the City of Los Angeles, or his designee, California Fire Chiefs Association, California Building Officials, Southern California Earthquake Center, California Resources Agency, California State and Consumer Services Agency, California Business, Transportation, and Housing Agency, and the United States Geologic Survey, the University of California, the California Institute of Technology;

IT IS FURTHER ORDERED that the California Seismic Safety Commission present the recommendations resulting from this collaborative effort by September 1, 1994;

IT IS FURTHER ORDERED that, in accordance with the authority vested in me by the California Emergency Services Act, and in particular, Section 8571 of the California Government Code, HEREBY SUSPEND the operation of all such statutes, rules and regulation as they apply to California Seismic Safety Commission contracts for the investigation and technical analysis required in fulfillment of this order.

IN WITNESS WHEREOF I have hereunto set my hand and caused the Great Seal of the State of California to be affixed this 9th day of February 1994.

ATTEST:

Governor of California

Secretary of State

Introduction

This report outlines affordable, common sense actions that can be taken to make our homes, schools, hospitals, places of work, freeways, and lifelines safer from earthquakes. It was developed in response to Governor Pete Wilson's Executive Order W-78-94 (Figure 1), issued after the Northridge earthquake struck the San Fernando Valley and surrounding areas. In issuing the order, Governor Wilson acknowledged that California has an opportunity to improve the policies, laws, programs, code enforcement, and professional practices across a broad front to manage our seismic risk. We should take full advantage of the time before the next destructive earthquake as a very brief window of opportunity to reduce our risk.

We cannot afford to rely on good fortune to minimize earthquake losses.

The magnitude 6.7 Northridge earthquake occurred at 4:31 on the morning of January 17, 1994, a national holiday, when most Californians were at home asleep (Figure 2 shows the epicenter and the affected area). Fifty-seven people lost their lives, nearly 9,000 were injured, and damage was in excess of $20 billion.

In many respects we were fortunate. The earthquake could have occurred during normal business hours, with freeways loaded to capacity, shopping centers crowded, people at work, and children in school. It also could have been larger; shaking could have lasted considerably longer and been felt over a much wider area. The number of injuries and deaths could have been much higher, and damage figures much greater. We cannot afford to rely on good fortune to minimize earthquake losses.

Figure 1. Executive Order W-78-94.

We must use the lessons from the Northridge earthquake to turn our losses to gains in seismic safety.

California is a world leader in reducing risks from earthquakes. We have a strong history of learning from earthquakes and building on that knowledge. We have developed a formidable technical expertise to design and build structures that withstand intense shaking, and we should be encouraged by the fact that the vast majority of structures did withstand this moderate earthquake and by the efficient response of the affected communities and agencies. Had such an event occurred in a similarly densely populated area outside California, the number of fatalities and injuries, as well as the amount of damage to structures, would have been immeasurably greater.

Nevertheless, California has not done all it can to reduce earthquake losses. The Northridge losses were enormous. Now we must use our knowledge and turn our losses from the Northridge earthquake to gains in seismic safety. We must vigorously pursue the actions recommended in this report. As Californians, we all share a critical responsibility to make our families, ourselves, and our surroundings safer from earthquakes. The vision and leadership necessary to provide an infrastructure that can withstand the forces of future earthquakes without unacceptable losses must be forged and carried out by our elected officials, policymakers, government agencies, professional organizations, and the professionals who deal with seismic matters on a daily basis.

Seismic issues must be placed in their proper economic, legal, and political context. There will always be risks from earthquakes. The Commission believes the keystone of a successful policy framework for mitigating seismic risk is to face the risk squarely, use available knowledge to the fullest possible extent, and to inaugurate common sense changes that will work in both the short and

DEVELOPING THE REPORT

Responding to the losses from the Northridge earthquake, Governor Pete Wilson issued Executive Order W-78-94 (Figure 1) instructing the Seismic Safety Commission to review the effects of the earthquake and to "coordinate a study of the specific policy implications . . . with particular attention to . . . seismic structural safety and land use planning." Furthermore, he directed the Commission to "avail itself of the expertise available from building design and construction professionals, as well as academia, by creating a process for the inclusion of . . . a number of public and private entities in the study." Governor Wilson emphasized how vital it is that we "learn all we can from this tragedy and, if possible, improve building seismic standards to protect life and property in future quakes."

In carrying out the Governor's mandate, the Commission used over three dozen background reports (published separately in the *Compendium of Background Reports on the Northridge Earthquake,* SSC 94-08) that describe the relevant laws, codes, regulations, and current practices in the fields of land use planning, structure and lifeline design, construction, and earth sciences. These reports were prepared by experts who reviewed the results of the Northridge earthquake and the legal, social, and physical environment in which they took place. The reports were also reviewed by over 60 stakeholders, from state agencies and professional organizations to private citizens. In addition, a number of detailed case studies were conducted on over two dozen buildings following the earthquake and published as *Northridge Buildings Case Studies,* SSC 94-06. The Commission also reviewed the effectiveness of the laws, codes, regulations, and programs dealing with seismic safety in California.

Figure 2. The triangle shows the epicenter of the January 17, 1994, Northridge earthquake.

long term. Solutions to reduce seismic risk must be both economically and technically feasible and be carried out by those with appropriate responsibility. Programs must have clearly defined objectives, clear lines of responsibility, adequate resources, solid plans of action, and external accountability.

This report calls for policy changes in land use planning and in the overall process by which we design and build structures and lifelines to resist earthquakes. Its recommendations call for high-priority actions by the Administration, the Legislature, government agencies, professional organizations, private business, academia, and individuals to reduce earthquake risk in California to acceptable levels.

Though most of these recommendations will be carried out by government agencies, earth scientists, and professionals in the building industry, every Californian should understand the importance of these measures and hold elected officials accountable for results.

CHAPTER I

Effects of the Northridge Earthquake

At 4:31 a.m. on January 17, 1994, eight miles below the surface of the northwestern end of the San Fernando Valley, an earthquake shattered the early-morning peace for millions of California residents. The magnitude 6.7 earthquake generated intense shaking that, although it lasted for only about nine seconds, caused widespread damage and enormous economic loss. The communities of Northridge, San Fernando, West Hollywood, Santa Clarita, Fillmore, Simi Valley, and Sherman Oaks were generally the hardest hit, but strong shaking and vulnerable buildings caused extensive damage as far away as central Los Angeles, Santa Monica, and Whittier.

Earthquake damage is usually described through losses and descriptions of damaged facilities, but in the end, it is people, businesses, institutions, and government that pay the price. This chapter is an overview of the effect of the Northridge earthquake on people, buildings, lifelines, and the local economy. It is these effects the Commission seeks to reduce in future earthquakes through improved public policy.

Downs, Los Angeles Times

% **Fire and water from broken pipes mixed on Balboa Boulevard.**

People

Although the number of lives lost in the Northridge earthquake was remarkably low considering the intensity of the earthquake and its location, 57 people died and nearly 9,000 were injured. The numbers of dead and injured were not as high as in some other natural disasters, but the earthquake affected the lives of more people than any previous natural disaster in the United States.

Tobin

Figure 3. Part of "ghost town" created by the earthquake.

The earthquake hit Californians hardest at home. Over 25,000 dwelling units were permanently lost or severely damaged, and over 1,600 homes and apartment buildings were declared uninhabitable. By mid-September the Governor's Office of Emergency Services and the Federal Emergency Management Agency (FEMA) had received over 630,000 phone calls regarding disaster assistance from victims of the Northridge earthquake, more than twice the number received after the previous record holder, Hurricane Andrew. FEMA had also received over 265,000 applications for individual and family grants. The Small Business Administration had conducted over 535,000 interviews with earthquake victims and had approved over 100,000 loans totaling nearly $3.4 billion.

OES

Figure 4. A red tag on a building after the Northridge earthquake.

Low-cost housing is proving the most difficult to replace. Despite extraordinary city, state, and federal government efforts, including offers of low- and no-interest loans, nine months after the earthquake, repairs have begun on less than half of the 507 buildings that provided 11,000 apartments in the now infamous "ghost towns" (see Figure 3). The owners of the remaining buildings either don't yet know whether they can rebuild or have decided to forfeit their equity and allow lenders to foreclose.

Many of those affected physically, mentally, and economically by the earthquake nevertheless regard themselves as fortunate, knowing that others suffered more, but for some the combined effects of change, fear, grief, and uncertainty on top of the stress of daily life create frustration and anger. Local mental health agencies and community-based groups reported over 1,150,000 crisis counseling interventions, costing over $35 million. Although most victims have adjusted and returned to an appearance of normalcy, for many the trauma continues.

Buildings

The Northridge earthquake was the most expensive earthquake in the history of this country, with losses estimated at $20 billion. The greatest portion of those losses was a direct result of damage to buildings. Over 112,000 structures were damaged in the earthquake. In the City of Los Angeles, over 93,000 buildings were damaged badly enough to require inspection, and nearly 2,000 (including 1,500 residential buildings) of those were red-tagged (Figure 4 is an example), forbidding entry; another 1,000 buildings were red-tagged in other affected communities. Over 8,800 buildings were yellow-tagged as safe only for limited use in Los Angeles; 5,000 more were yellow-tagged in other communities.

Although the earthquake damaged structures of nearly every type, most modern buildings (those built to post-1976 codes) performed significantly better than structures built to prior codes. However, three types of structures built to modern codes had a higher-than-expected frequency of damage:

1. Tilt-up concrete buildings
2. Steel moment-frame buildings
3. Aboveground reinforced concrete parking structures

The most severe damage generally occurred to buildings designed to codes used before 1976. The damaged buildings can be divided into three categories:

1. Buildings constructed with suspect materials and techniques, such as tilt-ups, nonductile concrete frames, and unretrofitted unreinforced masonry (URM).
2. Buildings designed or constructed with irregular configurations—for example, multistory buildings with inadequately braced first stories (like most of the apartment houses that collapsed) and hillside homes.
3. Buildings with poor design, construction, or maintenance.

In spite of the good performance of most buildings, the economic losses were high. The damage to nonstructural elements—heating and air conditioning systems, lighting fixtures, suspended ceilings, partitions, and equipment—was costly. Nonstructural damage is a significant matter because the value of these elements generally ranges from slightly over half of a single-family dwelling's cost to as much as 80 percent of the total cost of many large buildings. Nonstructural items make possible a building's function, and nonstruc-tural damage can disable buildings that are otherwise safe to occupy. Some hospitals had to close after the earthquake, even though they had suffered only minor structural damage, because of damage to sprinkler systems, power systems, and other vital equipment.

Fires

The earthquake caused relatively few fires, although the most spectacular, the fire at a break in a natural-gas transmission line on Balboa Boulevard, was shown so often on television that it gave the perception of a more pervasive problem. Good fortune played a critical role in keeping fires from spreading: there was no wind, and the area was not experiencing a dry spell. Another major factor, which was not a matter of luck, was the high level of planning and training in local fire departments and utilities, and the earthquake risk-mitigation programs of many businesses and governments.

Nevertheless, there were several problem areas:

- A number of fires in mobile home parks were caused when mobile homes fell from their supports and severed natural-gas connections. In all, 172 mobile homes were destroyed by fire. These mobile home fires were all too predictable; they remain a constant threat throughout the state.
- Communications failures hampered the response of emergency responders.
- Damage to water delivery systems seriously limited the efforts of firefighters.

Lifelines

Lifelines—transportation systems, communications, and water, gas, and electric utilities—suffered extensive damage. The effect of individual lifeline failures and combined failures is both direct (gas fires) and indirect (interference with emergency response). The combined loss of water pressure, electrical power, emergency power, and communications, coupled with significant gas-related fires, presents a clear and unacceptable hazard with far-reaching implications for emergency response and disaster recovery. Only good fortune prevented an even greater disaster.

Transportation Systems

Despite the retrofits and improvements in design that were made between the 1971 San Fernando earthquake and this 1994 event, some freeway overpasses collapsed and other portions of the highway system failed. Most of the bridges that

SAFETY EVALUATION CLASSIFICATIONS

Damaged buildings are rapidly evaluated after an earthquake to determine whether continued use is appropriate or whether hazardous conditions are present that should limit entry. More detailed evaluations generally follow, and with better information, the rating often changes. The ratings for buildings correspond to the color of the placard posted on the structure by the inspector to signify its condition (ATC, 1989):

Green: The building is posted as *Inspected.* Buildings in this category have no apparent hazard though repairs may be required. There is no restriction on use or occupancy.

Yellow: The building is posted as *Limited-Entry*. Buildings in this category are believed to have a dangerous condition, especially in an aftershock. Entry is limited to the owner for emergency purposes, but continuous usage and public entry are not allowed.

Red: The building is posted as *Unsafe*. Buildings in this category are believed to represent a life-threatening hazard or may be in imminent danger of collapse from an aftershock. Entry is limited to authorities only.

were severely damaged were designed prior to the changes instituted as a result of the San Fernando (1971) and Loma Prieta (1989) earthquakes. Bridges designed and built after the late 1970s performed relatively well. The direct cost to repair damaged freeway structures was over $350 million.

Emergency and normal communications systems were disrupted by damage, loss of electrical power, increased call volume, and call convergence.

Communications

Communications failures during this disaster resulted in breakdowns in service, misunderstandings, lack of information for making decisions, and, in some cases, loss of lives and property. Emergency and normal communications systems were disrupted by damage, loss of electrical power, increased call volume, and call convergence into and out of the affected area. The disruption ranged from delayed dial tones to nonfunctional radio systems. Cellular phones worked well, but experienced overload. Radio communication among various police and fire agencies was hampered by too few mutual-aid channels, incompatibility of dissimilar radio systems, and the use of exclusive frequency bands.

Many hospital radios and phones did not work, requiring the Los Angeles Fire Department to send runners and fire units to determine the status of hospitals; paramedic and emergency medical services in the San Fernando Valley had communications problems; the Los Angeles County Medic Alert Center broke down; the Hospital Emergency Administrative Radio system was inoperable in the area of greatest earthquake impact; Reddi-Net, a computerized system owned by the Hospital Council of Southern California that links 86 hospitals, failed. Equipment damage and lack of employee training took their toll.

Electricity

About two million customers in the Los Angeles area lost electric power following the earthquake. Although power to most customers was restored, those near the epicenter, including hospitals and police and fire stations, were without power. Electric utilities made significant progress in "hardening" their generating and distribution facilities as a result of lessons learned in the San Fernando, Loma Prieta, and other earthquakes, but this event presented new problems. For the first time, transmission towers were toppled at a few locations. Power was restored to most of the region within one day and the hardest-hit areas within three days.

Gas

Damage to natural-gas transmission and distribution systems caused fires, including a spectacular fire on a major thoroughfare, and interrupted service. The earthquake demonstrated that some older pipelines are vulnerable to failure in areas of ground deformation, but that newer pipelines faired well. Because gas-related fires are a major source of losses, efforts to minimize losses and control leaks are important.

Water

Damage to the area's water supply systems, from northern California and the Colorado River, as well as to distribution lines interrupted supplies and hampered fire fighting. The earthquake damaged five major aqueducts, disrupting the supply from the north. These pipelines serve treatment facilities that prepare water for the areas of Santa Clarita, Simi Valley, and San Fernando Valley. As was the case following the 1971 San Fernando earthquake, significant repairs were also required on local water distribution systems. Water was unavailable to some of the areas hardest hit by the earthquake for several weeks.

The Economy

The $20 billion in losses that often has been quoted as the cost of the Northridge earthquake covers, primarily, the physical damage to structures and lifelines. It does not include many of the costs related to loss of use, loss of business, loss of productivity, and relocation of businesses. Though they are significant, these losses are often overlooked. It was estimated that the loss of use of parts of the transportation system following the earthquake cost $500 million in delays and lost productivity.

Overall productivity losses in the Los Angeles

area in the days following the earthquake were estimated at $1 billion (Romero, 1994). Indirect economic effects such as loss of tax revenue, short- and long-term loss of productivity, and ripple effects such as foreclosures, abandonment of equity, and redistribution of commercial activities are extremely difficult to calculate with any degree of accuracy. Such imprecision doesn't lessen the impact, especially to the victims.

Loss of businesses is creating major problems in some areas, where these businesses provided both needed services and jobs. Although some businesses, trades, and professions are seeing an increase in demand for their services and products, fueled in part by government grants, low-interest loans, and other assistance, many small businesses remain closed or are struggling because the nearby residential properties that housed their normal customer base remain vacant. Nine months after the earthquake, nearly 50 percent of the small businesses in the most heavily affected area of Northridge were still not open. The commercial district in Fillmore and many commercial properties in communities from the San Fernando Valley to Santa Monica still awaited repairs.

Insured losses exceeded insurance industry expectations, illustrating the importance of reducing earthquake risk. The California Department of Insurance estimates that over 300,000 claims for earthquake damage repair had been filed as of October 1, 1994. The size of individual claims from the Northridge earthquake has been, on average, two or three times greater than claims from previous earthquakes. Insurance companies expect to pay approximately $11 billion in claims, and some have been driven to the brink of insolvency. Many insurance companies, believing their earthquake insurance risk exceeds their ability to pay future claims, have moved to limit the number of policies written for earthquake and homeowners' coverage in California. Lasting effects will be felt in terms of the availability of insurance, the amount paid for premiums, and the quality of coverage.

Conclusions

The Northridge earthquake was shocking—but predictable. The intense shaking caused severe damage—damage that could have been much worse. Many owe their lives and lack of injuries to the earthquake's timing. Thinking of the consequences if it had struck when schools, workplaces, and freeways were at capacity should force all Californians to new awareness and resolve. As it is, the millions of people affected will recover in time. Debts are being paid. Recovery should, indeed *must*, bring such healing, but it should not cause us to forget.

The Northridge earthquake was a reminder. It showed us—again—how devastating even a moderate urban earthquake can be. Scientists also remind us that California's urban areas will continue to experience such earthquakes. Some of them will be just as intense as Northridge—but may last longer, causing a wider area of damage and destruction. They may occur at times when freeways, office buildings, and schools are filled with people.

The recommendations in this report propose actions so that California will be less vulnerable to such events.

The intense shaking caused severe damage—damage that could have been much worse. Many owe their lives and lack of injuries to the earthquake's timing.

CHAPTER II

Geologic and Geotechnical Aspects of the Northridge Earthquake

The Northridge earthquake occurred at a depth of approximately nine miles beneath the earth's surface on a buried, or "blind," thrust fault. It produced intense shaking and caused extensive damage that reaffirmed the potential risk from this type of fault—and the need to mitigate that risk.

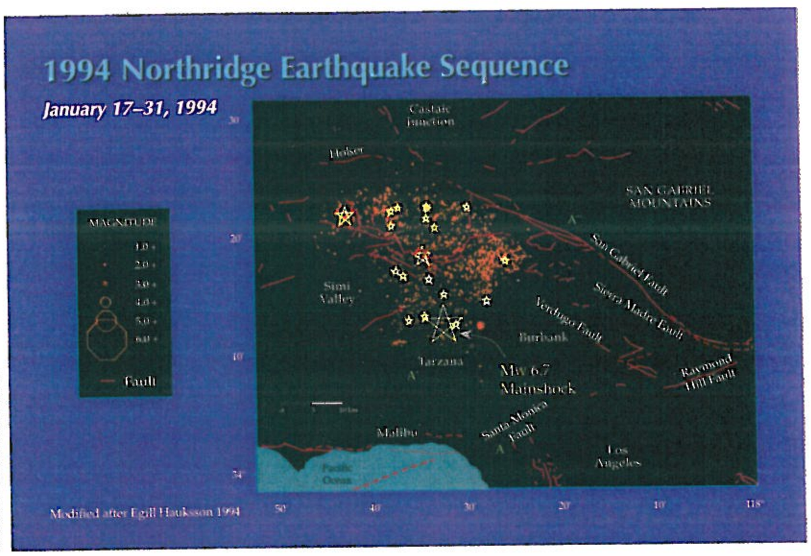
The earthquake was the most recorded earthquake that has ever occurred in California. Figures 5 and 6 show two perspectives of the data obtained. Strong-motion instrument recordings were obtained at 257 sites. Over 11,000 aftershocks have been recorded by these instruments. By maintaining and enhancing data collection programs and identifying areas that have faults capable of causing earthquakes, California can learn to better reduce its seismic risk.

The Northridge earthquake also caused secondary hazards, the most prominent of which was localized amplification of the ground motion caused by local geologic conditions. The identification and mitigation of secondary hazards, such as landslides, liquefaction, and areas that may amplify shaking, need to be integrated into land use planning programs, building codes, and engineering practices.

◄ Sand boils caused by the earthquake at Redondo Beach.

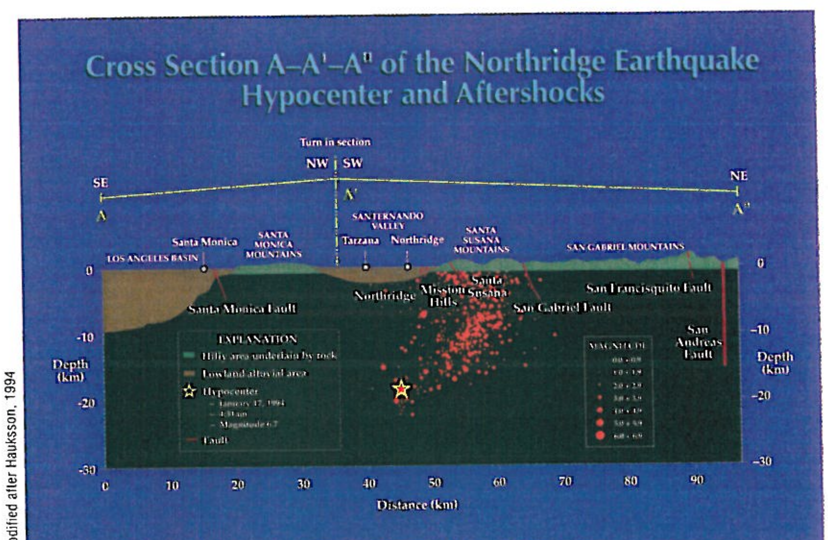
Most of the hazard associated with earthquakes typically comes from strong shaking.

The Northridge earthquake provided many geologic, seismologic, and geotechnical data that are still being compiled and analyzed. A significant value of the Northridge earthquake data is their use in the development and calibration of methods for assessing seismic hazard for planning and engineering applications. For example, the Northridge event occurred on a buried fault, highlighting the need to characterize and include earthquakes on this type of fault in the analysis of the ground motion component of the overall seismic hazard. It also reaffirmed that most of the hazard associated with earthquakes typically comes from strong shaking.



Modified after Hauksson, 1994

Figure 5. Map showing Northridge earthquake sequence over a two-week period.



Modified after Hauksson, 1994

Figure 6. Cross section showing Northridge earthquake hypocenter and aftershocks.

Using Geologic Information

Seismic hazard analyses are becoming more useful as our knowledge of the geologic aspects of hazard and source characteristics increases. Local conditions can affect the level of hazard significantly. It is now more common in ground motion hazard analyses to represent seismic sources as three-dimensional faults and to characterize the faults by their possible rupture dimensions, slip rates, and recurrence rates. Simplified approaches may be adequate, and in some cases necessary, for national-scale seismic hazard studies, but they can be enhanced for regional hazard assessments. Seismic hazard analyses for particular sites (such as for critical facilities) have long included details of potential nearby earthquake sources and other site-specific information.

In addition to integrated representations of seismic hazards, such as ground motion maps for a particular return period, geologic information can be used to develop earthquake scenarios that can be useful for many applications. The California Division of Mines and Geology (CDMG) has prepared earthquake scenarios to evaluate emergency response in the San Francisco Bay Area, southern California, and northwestern California. With appropriate modifications, such scenarios also could be used to assess potential damage to residential, commercial, and industrial development, as well as estimate loss of lives and damage to the infrastructure. The scenarios could include details of earthquake effects for engineering purposes, as well as expected damage for emergency response and land use planning purposes.

At present, California is implementing a program to mitigate surface fault rupture hazards (the Alquist-Priolo Earthquake Fault Zone Act), but is only in the early stages of developing maps under the Seismic Hazards Mapping Act (SHMA) to address the shaking, landsliding, and liquefaction hazards. The Northridge earthquake emphasizes the need to address these higher-priority hazards; the Commission believes

CDMG's Strong Motion Instrumentation Program proved its worth during this earthquake and its aftermath.

accelerations in this earthquake were especially high, most spectra generally agreed with those recommended by site-specific geotechnical studies as the basis for the design of special structures. Similar response spectra have been calculated from data from numerous earthquakes since the 1971 San Fernando event and should be expected in future events.

Engineers use *design* spectra to determine the design parameters to use when designing structures. The values for design spectra are not the same as those of response spectra computed from measured ground motion. Design spectra are modified from response spectra to reflect safety factors and the performance of materials and structural systems observed in past earthquakes.

Because of the damage from this earthquake, questions have been raised concerning the adequacy of the building code's definition of the forces that earthquakes can impose on buildings. Code writers and designers know that code spectral values will likely be exceeded in large earthquakes and that this was anticipated when the code was written.

The recorded data from the Northridge earthquake are still being evaluated and are subject to different interpretations. Strong motion instruments also were not located in many of the areas that suffered the most severe damage. Generally speaking, the motions recorded near the Northridge epicenter were compatible with those used as the basis for the code, but the motions exceeded those assumed in the code in some cases. At some locations, particularly in the near-source area and in areas with unique local geology, shaking exceeded the assumptions underlying design values in the short- to mid-period range. This shaking appears to have affected low- and mid-rise buildings and caused response in higher modes of vibration for tall buildings. Velocity- and displacement-sensitive structures also may have been affected by the velocity pulses described earlier. Near-source and local geologic effects must be considered in the design of structures. There is no compelling evidence that changes to the code's assumed force levels are necessary. However, changes are necessary regarding the treatment of the effects of near-source and local geologic conditions.

Strong-Motion Instrumentation

The timely release of strong-motion data, especially during the days immediately following an earthquake, is invaluable to building owners, emergency responders, and those who will revise codes and design practices. Much of the evidence of an earthquake's effects disappears quickly as demolition, repair, and reconstruction take place. The opportunity to compare building performance and earthquake effects with actual motion data helps practicing engineers and researchers understand their observations, which in turn helps strengthen building codes and reduce future earthquake damage.

The Commission believes that the CDMG's Strong Motion Instrumentation Program (SMIP) proved its worth during this earthquake and its aftermath. Within a day of the main shock, SMIP had issued a "Quick Report" containing copies of strong-motion records obtained by four of its stations; copies of records for nine additional stations were released the following day. By the third day, copies of records for 28 stations had been made available, and by January 25, five quick reports had been released, providing peak acceleration data for 68 stations. In mid-February, SMIP issued a report containing pertinent station information, known geologic site conditions, peak acceleration data, and traces of recordings from 193 stations. SMIP also processed significant records rapidly and released processed data from five stations during the first week of February; additional releases followed at three- to four-week intervals. Processed data for more than 70 stations were released by December 1994. The timeliness and quality of these data were extremely valuable.

The U.S. Geological Survey (USGS), utilities, dam owners, and researchers funded by the National Science Foundation (NSF) operate networks of hundreds of free-field and structural strong-motion instruments scattered throughout California. A considerable public investment

DEFINITIONS OF NEAR-FIELD AND NEAR-SOURCE

The terms "near-field" and "near-source" are often used interchangeably by engineers and others to represent an area near the fault where earthquake shaking has characteristics that differ from the shaking expected at greater distances. However, some seismologists use the term near-field differently from the way many engineers do. To clarify these terms, the following definitions are used in this report:

Near-Source Area: The near-source area is the area of the ground surface lying above and adjacent to the fault rupture plane. Its horizontal extensions from the fault are about the same as the depth of the rupture on the fault.

Near-Field: Near-field is a mathematical term used in seismology to describe the characteristics of waves propagating from a fault rupture.

Near-Source Effects: Ground motion in the near-source area may be characterized by high accelerations, large velocity pulses, and permanent tectonic displacement. The nature of ground motion is related to the direction and mechanics of the fault rupture as well as the path of the seismic wave to the site. The characteristics of near-source shaking may be quite different from those of more distant earthquakes and may not follow the "normal" attenuation relationships used to describe shaking at more distant points. The ground surface in the near-source area may experience slow deformation before the earthquake and will be warped permanently by the rupture of the fault during the earthquake.

causes significant high-frequency motion and allows permanent coseismic displacement of the fault and surrounding area. Known as source-effect phenomena, these factors affect the amplitude and frequency content of shaking.

Of critical importance to the design of engineered structures is that near-source effects combined with local geologic effects can adversely alter the seismic performance of a wide range of structures, including highrise and base-isolated buildings. Data recorded during the Northridge earthquake clearly indicate the need to incorporate measures to mitigate this hazard in building codes. High-velocity pulses in the near-source area are believed by some to be a cause of much of the damage. These pulses were the largest in the northern San Fernando Valley and Santa Susana Mountains. They were also significant in the southern San Fernando Valley.

Duration of Strong Motion

The longer ground shaking lasts, the greater the damage to structures, natural slopes, and fills. When strong shaking ceases, there is a reasonable possibility that the damage will not continue. However, if the shaking continues after damage has been initiated, structures will continue to degrade and may eventually collapse. Damage caused by seismic consolidation and liquefaction also increases as duration increases. The duration of intense shaking during the Northridge earthquake was relatively short, on the order of nine seconds or less. Had the earthquake's magnitude been larger, there is little doubt that strong shaking would have lasted longer and the damage would have been greater. Strong shaking has lasted minutes in some other events.

The duration of intense shaking, like near-source effects, is not explicitly considered in our building codes. Because an urbanized area of California has not yet been exposed to long-duration near-source effects, the effect of duration on various types of structures is not fully understood.

Response Spectra

Response spectra are graphs that display the response of structures to ground motion associated with earthquakes (Figure 9 is an example). A spectrum graphically depicts the variation of spectral accelerations (velocities or displacements) experienced by simple structures with different stiffnesses or periods of vibration (expressed in seconds). Although some recorded

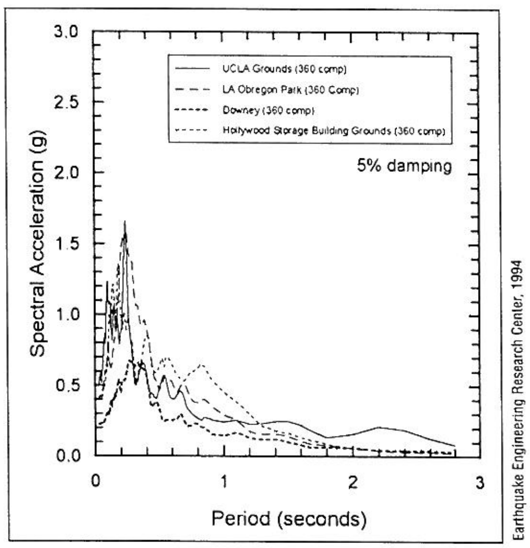


Figure 9. Example of Northridge earthquake response spectra.

There was initial speculation that much of the damage in the Northridge earthquake was caused by abnormally high vertical accelerations. Vertical accelerations tend to be comparable to or exceed horizontal accelerations near the area of fault rupture. Although vertical accelerations were high in some locations, so was the horizontal acceleration. The ratio of vertical to horizontal accelerations was consistent with previously recorded data. Modern building codes are based on assumptions that the maximum vertical accelerations will be two-thirds of the peak horizontal acceleration. An analysis of CDMG's Northridge records indicates that, although this ratio was exceeded at a number of locations, on average, it held true (Shakal et al., 1994). The Commission has not received evidence that vertical accelerations played an unusual role in the damage caused by the Northridge earthquake.

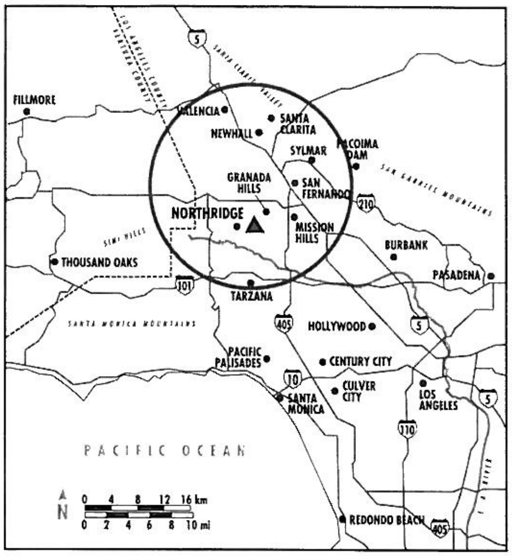


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Figure 8. Map showing preliminary near-source area (circle) for the Northridge earthquake.

Velocity and Displacement

The intensity of shaking is typically described by acceleration recordings. The Northridge earthquake also produced high velocities and displacements not described in acceleration data. A velocity of 56 inches per second was recorded in a parking lot at the Sylmar County Hospital, and a velocity of 72 inches per second was recorded at the Rinaldi receiving station. Peak velocity is important because it is a good indicator of an earthquake's demand potential (or energy) on multistory structures.

Ground displacement also is a significant factor in the design of structures, especially for seismically isolated structures. Ground displacement of 31 inches was measured at the Sylmar County Hospital parking lot. Base-isolated structures are normally separated from the surrounding soil to allow room for movement. Although seismically isolated structures are isolated from high-frequency shaking during an earthquake, they may collide with building foundation stops or barriers if actual displacements exceed the anticipated or design displacements. Such collisions would result in high impact forces that can cause significant damage and even collapse.

Near-Source Effects

The near-source region of an earthquake can be defined as the region within several miles of where the projection of the fault rupture plane meets the ground surface. Figure 8 shows the approximate near-source area of the Northridge earthquake. Within this region, the ground motion may be characterized by pulses of high velocity that are potentially damaging to certain types of structures. The near-source area in a strike-slip earthquake would have a different shape (generally longer and narrower, extending on both sides of the fault rupture for the length of the rupture), and the nature of the near-source strong motion would also vary, depending on other nonsource effects such as local geologic conditions.

Although seismologists have known of the influence of near-source effects on seismic shaking for some time, near-source effects first gained the interest of California engineers following the 1971 San Fernando earthquake. Failure of the Olive View Hospital in 1971 was attributed, in part, to a large, long-period near-source "seismic pulse." Near-source effects have been considered in the design of some critical facilities for a number of years. However, the implications of near-source effects have only recently been studied for use in the design of conventional structures because previous earthquakes have not struck well-instrumented urbanized areas and, therefore, produced few recorded motions from areas close to the source. At present, near-source effects are not explicitly considered in the building codes except for seismically isolated structures.

Near-source effects of engineering interest are related to the direction and mechanics of the fault rupture. The numerous localized, relatively rapid failures of "patches" of the fault surface

that the SHMA program is a vital part of the state's efforts to mitigate seismic risk and should be funded at a higher level to accelerate its progress. The Alquist-Priolo and SHMA programs are discussed in more detail in Chapter V.

The Commission believes that a broad base of support for the hazard mapping program must be established in the earth sciences, engineering, financial, and planning communities so that its products will be used effectively. Better lines of communication must be established among scientists conducting hazard analyses, engineers using the results in design and review, and planners who implement the results for land use planning. The Commission believes it is also important that the results of the mapping program be implemented at the planning stages of land use and not solely at the later building and safety stages. Recommendations addressing these concerns are also included in Chapter V.

Recommendations

The Commission recommends that:

- CDMG use independent peer review by acknowledged experts representing scientists, hazard analysts, and users throughout the Seismic Hazards Mapping Program.
- CDMG draw on resources outside state government to conduct the mapping program.

Strong Ground Motion

The Northridge earthquake was a moderate earthquake that produced strong ground motions and intense shaking. The term "moderate" describes the *magnitude* of the earthquake, which in this case was 6.7. Moderate earthquakes (less than magnitude 7.0) generally produce localized shaking of an intensity (that is, amplitude of motion and frequency content) on stiff structures similar to that of major earthquakes (magnitudes of 7.0 and above). However, a more extensive area experiences intense shaking in a higher-magnitude earthquake and the *duration* of the shaking, the length of time the strong motion lasts, generally increases with increases in magnitude. Since a higher-magnitude earthquake affects a larger area and lasts longer, it can be expected to cause greater damage. Figure 7 compares areas subjected to intense shaking from four earthquakes, including Northridge.

A number of factors affect the amount of damage to structures in an earthquake, but the intensity of shaking is of paramount importance. Shaking intensity is affected by the magnitude of the earthquake, its style of faulting, local geologic conditions, proximity to the fault rupture, and the rupture geometry along the fault. The Northridge earthquake's strong-motion records reveal extensive information about the nature of the shaking, including acceleration, velocity, displacement, duration, and frequency. The consensus of earth scientists and geotechnical engineers is that the earthquake's motions were not unusual for a thrust-fault earthquake of this magnitude. However, this earthquake clearly points out the importance of near-source effects and local geologic conditions on shaking intensity and the need to incorporate these phenomena in seismic design and construction.

Accelerations

Peak accelerations, which are not necessarily the best measurement for correlating ground motion with the forces in structures, typically ranged from 0.4g to 0.8g in the regions that suffered significant damage. Recorded peak horizontal accelerations typically ranged between 0.1g and 0.5g at distances between 12 and 30 miles from the rupture zone, although some higher accelerations were recorded due to local geologic or topographic conditions. Horizontal accelerations exceeding 0.9g were recorded in the San Fernando Valley and in Santa Monica, nearly 14 miles away from the epicenter. The highest recorded free-field accelerations, 1.82g horizontal and 1.18g vertical, were at the Cedar Hill Nursery in Tarzana, three miles south and west of the epicenter. Instruments near an abutment to the Pacoima Dam recorded peak accelerations of 2.3g horizontal and 1.7g vertical, although the free-field accelerations on alluvial materials near the base of the dam were less than 0.5g.

Figure 7. Map showing the area of intensity level VII and greater for selected historic California earthquakes.

has been made in developing and maintaining USGS- and NSF-funded strong-motion networks. For example, the USGS strong-motion network in southern California consists of nearly 100 stations, while the University of Southern California network originally consisted of 80 free-field stations. Many of these instruments are old analog-type devices; the data they collect require considerable processing before they can be used. Because these arrays complement the SMIP instruments and record motion in different areas, data from these networks are vital to understanding the distribution and severity of shaking resulting from the earthquake. The USGS released photocopies of records obtained from 150 individual accelographs in February 1994. However, data from the USGS- and NSF-funded networks were not processed in a timely manner following the Northridge earthquake. USGS data were released to the scientific and engineering community in December 1994, but NSF-funded data were not released as of that date. This situation is unacceptable; a mechanism is urgently needed to correct this problem.

Recommendations

The Commission recommends that:

- The state continue its strong support of SMIP as a valuable part of California's effort to reduce the risk from earthquakes.
- SMIP exert leadership by organizing a workshop involving the other operators of strong-motion instrument networks in California to coordinate the deployment and operation of these networks.

  As a result of the workshops, SMIP should compile a list of all strong-motion instruments and their locations in the state and find ways to improve the overall performance of the systems. Furthermore, a mechanism should be developed to provide the processed data from earthquakes in a timely manner. These tasks should be completed by July 1995.
- Public funds not be used for the purchase, deployment, or upgrading of strong-motion instrument networks operated by private organizations unless there is a plan for the maintenance of the instruments and an agreement for the timely release of data to the public.

Reference Stations

Most free-field strong-motion stations were installed in locations near active faults to collect data for use in understanding the physics of earthquakes to be better able to estimate ground motion in future earthquakes. Such studies are vital to an understanding of the earthquake process, and such instrument deployments need to continue. However, there is also an urgent need for free-field strong-motion data as references to establish the levels of ground shaking experienced by buildings and other structures. Without such data, engineers cannot assess whether buildings performed as intended and determine the changes needed in codes and design practices to improve performance. For example, there were few free-field instruments in the immediate vicinity of damaged steel-frame buildings, so the levels and character of shaking experienced by these buildings are not well understood. The lack of reliable ground-motion data makes it extremely difficult to understand the causes of these failures and find acceptable solutions. None of the existing programs is directed toward obtaining the reference ground-motion data that are needed.

A mechanism is urgently needed to ensure the timely release of strong-motion data after an earthquake.

Recommendation

The Commission recommends that:

- SMIP give high priority to establishing a network of reference stations to measure ground motions in major urban areas of California.

  The reference station network should provide ground shaking data for use in the evaluation of building and structural performance after damaging earthquakes. Instruments deployed in this network should provide data that require a minimum amount of processing and will be available to building officials and engineers on an urgency basis.

Buried Faults

Like the 1983 Coalinga and 1987 Whittier Narrows earthquakes, the Northridge earthquake resulted from slip on a buried, or "blind," fault. Unlike surface faults, this type of fault remains completely buried deep in the earth's crust.

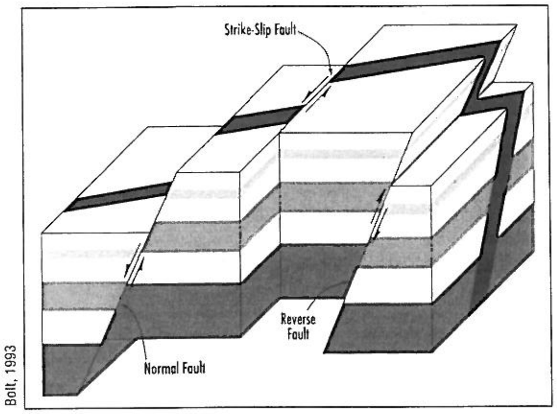
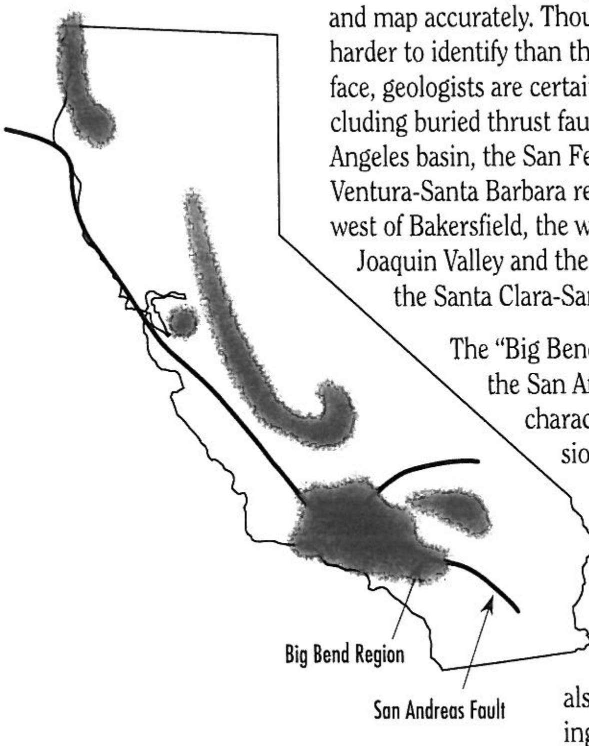


Figure 10. Diagram showing the three main types of fault motion.

Many faults break the surface; examples are reverse-slip faults of the type involved in the 1971 San Fernando earthquake and strike-slip faults such as the San Andreas, Hayward, and San Jacinto (Figure 10). Buried faults do not reach the surface even though they may be active. Buried faults can remain deep within the earth's crust, often at depths greater than six miles, or may extend to within a few hundred feet of the surface, so they are difficult to locate and map accurately. Though buried faults are harder to identify than those that break the surface, geologists are certain that buried faults (including buried thrust faults) lie beneath the Los Angeles basin, the San Fernando Valley, the Ventura-Santa Barbara region, areas south and west of Bakersfield, the west sides of the San Joaquin Valley and the Sacramento Valley, and the Santa Clara-San Jose area (Figure 11).

Figure 11. Regions of California with known buried faults.



The "Big Bend" (Figure 12) region of the San Andreas fault system is characterized by compressional features, including reverse faulting and folding in the Los Angeles Basin. Buried faults are significant components of the system. Other fault zones also are important, including zones of incipient faults (faults that are in the early stages of development) and subtle faults in alluvial regions. These faults show little direct evidence of existence on the surface but may be deep-seated, buried strike-slip or oblique-slip faults or their lateral extensions.

Geologists are able to recognize geomorphic features, such as broad ripple-like folds, or pressure ridges, and Riedel faults at or near the surface as evidence for the existence of buried faults. These folds and buried faults are produced by tectonic compression over millions of years. However, most fault studies have emphasized locating the surface traces of active faults. At the state level, the emphasis has been on identification of active strike-slip faults to mitigate surface fault rupture hazards under the Alquist-Priolo Earthquake Fault Zone Act, discussed in Chapter V.

Though the shaking above a buried fault can be severe, the size of the region of strong shaking is not typically as large as that from a large magnitude earthquake on a fault like the San Andreas. Regardless of the size of the affected areas, the tectonic compression causing thrust fault earthquakes is continuing, and many such faults are located under highly urbanized areas. Buried faults pose a serious hazard to the citizens of California.

Buried and other obscure faults are not a new threat. They have been considered in the design of certain critical facilities for over two decades. However, building codes do not explicitly address specific types of faults or near-source effects. Similarly, buried faults, near-source effects, and local geologic conditions have not been properly considered in hazard-mapping efforts, land use planning, or environmental reviews.

The Commission believes buried faults, near-source effects, and local geologic conditions need to be recognized as a significant part of the seismic hazard in California. The results of studies on these features should be incorporated in regional seismic hazard analyses and considered in the design of important buildings and structures. For example, the SHMA program and the Building Seismic Safety Council's effort to develop seismic shaking hazard maps for the 1997 National Earthquake Hazard Reduction Program's *Recommended Provisions for the Development of Seismic*

Regulation for New Buildings should incorporate provisions for sites near buried faults as well as near-source effects and local geologic conditions.

Recommendations

The Commission recommends that:

- CDMG identify areas where active buried faults exist that may cause serious damage and loss of life. By December 31, 1995, CDMG should conduct short-term, focused studies including:
  - Mapping of geologic and geomorphic indicators of buried faults (for example, pressure ridges and sag ponds).
  - Compiling subsurface geologic, geophysical, seismological, and geodetic data and analyzing these data and knowledge of active tectonics.
- CDMG form an advisory working group of knowledgeable earth scientists to develop cost-effective methods for assessing the locations as well as the significance of buried faults, the potential for earthquakes of various magnitudes, and motion parameters.

Site Conditions

Local site conditions, regional geologic conditions, and geomorphic features play an important role in the frequency and intensity of earthquake shaking and the potential for liquefaction, landslides, and subsidence. A significant part of the SHMA program is directed at mapping urban areas of the state that are subject to earthquake-induced landslides, liquefaction, or amplified shaking due to local conditions. The Commission believes it is important to complete this work quickly and competently, using the best technical resources available.

The amplification of strong ground motion because of geologic conditions is of major concern. In the Northridge earthquake, a section of Los Angeles' busiest freeway collapsed. The Santa Monica Freeway was built over an area aptly named "La Cienega"—Spanish for "the swamp." The motions that brought this section of the freeway down were, in all probability, amplified by the underlying soft soils and local geologic conditions.

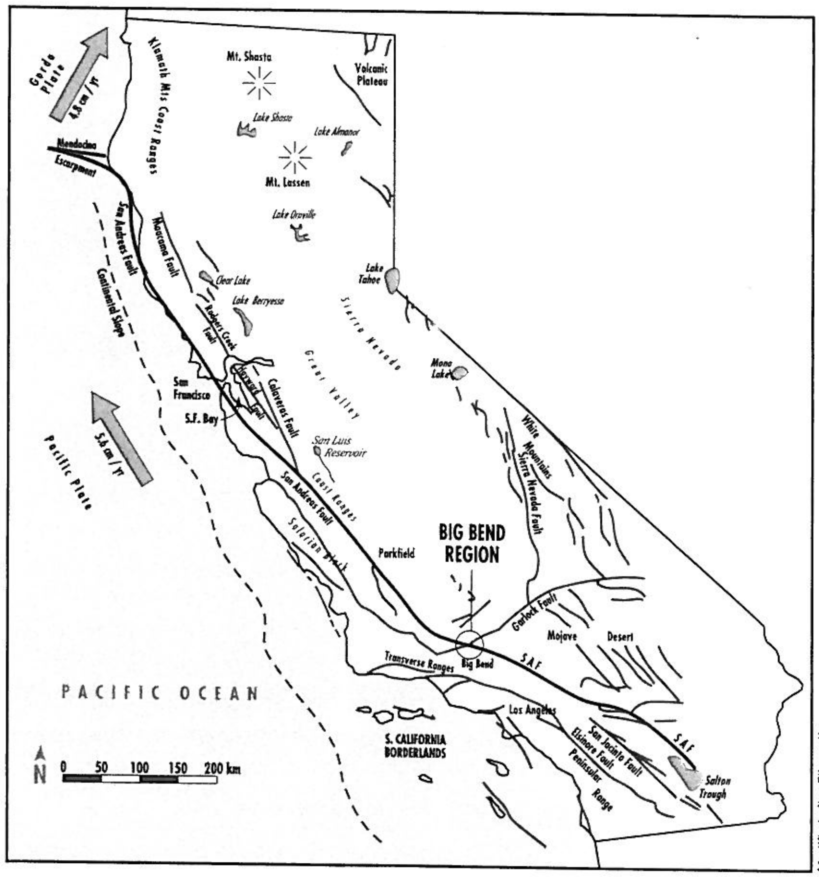
Decision makers and regulators must be aware of local geologic conditions and take them into account when planning, zoning, designing, and constructing buildings and other structures.

Recommendation

The Commission recommends that:

- Building codes, standards for design and retrofit of lifelines, and land use planning incorporate measures to identify and set priorities to reflect adverse seismic effects of local site conditions.

Figure 12. Map showing "Big Bend" area of the San Andreas fault.



Modified after Ellsworth

Ground Deformation

A zone of ground deformation near the Northridge earthquake's epicenter was marked by linear patterns of failed gas and water lines; compression and extension of streets, curbs, and sidewalks; concentrations of high building dam-

Buried faults pose a serious hazard to the citizens of California.

age; and a pattern of northwest- and northeast-trending breaks in the ground's surface. Surface displacement was generally an inch or two of right-lateral slip and up to four inches of left-lateral slip. There was about 12 inches of both compression and extension deformation. This pattern of deformation may be of tectonic origin or the result of locally severe near-surface shaking related to the buried fault rupture propagating and concentrating more intense seismic energy in localized areas.

In the Granada Hills District of the San Fernando Valley, USGS reported evidence of permanent ground deformation consisting of pavement cracks, depressions in the ground, pavement humps and tented sidewalks, and left-lateral offset of curbs along an east-west zone approximately three miles long and several hundred yards wide (USGS, 1994a; USGS, 1994b). This zone may be coincident with the mapped trace of the Mission Hills fault (Angell et al., 1994). USGS commented that the deformation might be related to arching and extension above a concealed fault or to lurching and differential compaction from strong shaking.

There are significant questions regarding whether the mechanisms causing the zones of permanent deformation were tectonic or nontectonic and what geologic tools are available for identifying these zones in advance of future earthquakes. If patterns of ground deformation are nontectonic, they may be explained as being related to zones of strong shaking that caused yielding of the soils at depth, leading to cracking and deformation of the surface materials. But if these zones are related to subtle faulting, they may add slightly to the area's seismic hazard (Barnhart and Slosson, 1973).

Zones of ground deformation detected near the epicenter may be related to tectonic folds and faults or to strong shaking. This deformation may signify a zone of subtle faulting that is the surface expression of deeper-seated strike-slip faults or perhaps the lateral extension of such faults. The boundaries of the zones should be identified and the amount of surface displacement and ground deformation and the damage they might cause in future earthquakes should be estimated. Urbanized areas obscure the identification of subtle fault zones, but patterns of deformation (cracked streets and sidewalks), geomorphic features (pressure ridges, compression-extension strain patterns), and earthquake damage patterns may be interpreted to infer their presence.

Recommendations

The Commission recommends that:

- CDMG, as part of its SHMA program, evaluate the level of hazard presented by possible subtle faults, buried faults, and incipient faulting in alluvial basins in active tectonic environments and zones of compression.

  Other types of tectonic deformation noted above are recommended as priority long-term research projects.

- CDMG, as part of its SHMA program, and under the policies of the State Mining and Geology Board, expand the categories of seismic hazards to create a new hazard zone to address ground deformation and amplified shaking associated with folding and faulting.

Natural Slopes, Unconsolidated Sediments, and Engineered Fills

Landslides, soil liquefaction, and ground settlement occurred in many areas during the Northridge earthquake. Many of these ground failures occurred in urban areas and contributed significantly to property damage. An area susceptible to landslides, liquefaction, and settlement can usually be recognized by the existence of factors such as geomorphic features, folding of youthful geologic units, and groundwater levels.

Landslides

The Northridge earthquake triggered landslides and rockfalls over an area of about 3,600 square miles, causing many road closures and significant damage to homes and utilities:

- Landslides damaged hundreds of homes on the crest and north flank of the Santa Monica Mountains between Cahuenga Pass and Sepulveda Pass.
- The Porter Ranch portion of the Santa Susana Mountains also experienced landslide damage.
- In the coastal bluffs of the Pacific Palisades in Santa Monica, several homes were destroyed or condemned because of landslides.
- A section of the northbound lanes of the Pacific Coast Highway remained closed for at least four days following the earthquake because of landslides.
- Many road closures were reported throughout the San Gabriel and Santa Susana Mountains.
- At least two electric transmission towers collapsed as a direct result of rock slides.
- A major aboveground natural-gas pipeline was damaged (EERI, 1994b).

The number of landslides resulting from this earthquake was consistent with other earthquakes of this magnitude, and the types of slides (rockfalls and deep-seated slumps) were comparable to those observed previously in similar geologic units and slope conditions. Geologic maps of the northern San Fernando region indicate geologic units containing weak materials and old landslides that might be reactivated, so areas susceptible to landsliding because of earthquake shaking can be readily identified and mapped.

Liquefaction

Soil liquefaction and related lateral spreading associated with the Northridge earthquake occurred in many areas but made a relatively small contribution to structural damage because they occurred in areas away from most buildings. Along the coast, liquefaction-induced sand boils were observed as far north as Calleguas Bridge, near the Mugu Lagoon, and as far south as Redondo Beach-Kings Harbor and the Port of Los Angeles. Inland, liquefaction-induced sand boils were observed near the epicenter and as far north as the Santa Clara River valley. This type of ground failure may have contributed to reported service-line breakages and to roadway, curb, and structural damage. For example, liquefaction-induced lateral spreads associated with horizontal displacements of about three inches and settlements of a few inches contributed to significant structural damage to a shopping center in Woodland Hills and a commercial building in Studio City.

Engineered Fill

Ground settlement without evidence of lateral spreading was observed at a number of sites following the Northridge earthquake. This settlement, which damaged many structures and service lines, may have been caused by soil liquefaction at depth, seismic consolidation, or induced compaction of engineered-fill materials or natural soil deposits.

Ground settlement, which damaged many structures and service lines, may have been caused by induced compaction of engineered-fill materials.

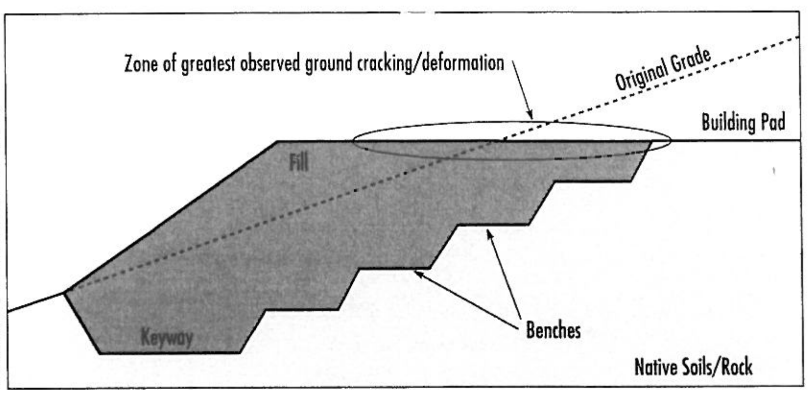
Structures located on engineered fills are common throughout California. A study by the Earthquake Engineering Research Center concluded (see Figure 13):

> The poor performance of modern wedge fills located on the faces of slopes during the Northridge earthquake is of considerable importance to the geotechnical engineering profession. The standards of practice in the construction of these fills have evolved considerably since World War II to address troublesome static failure, or long-term static distress, mechanisms such as landsliding and settlement. Modern design and construction practices in this region typically include drainage provisions and construction under the direction of licensed civil engineers. While these practices have generally improved the static performance of fills, the potential for poor dynamic performance has not been widely recognized. With the data collected following the Northridge earthquake, it appears that further evolution of the standards of practice may be necessary for the proper design and construction of wedge fills in seismically active areas (EERC, 1994c).

The Metropolitan Water District's Jensen Filtration Plant, located about six miles from the epicenter, was taken out of service after the earthquake as a result of the rupture of the influent conduit, an 85-inch-diameter steel pipe. The rupture occurred near the eastern boundary of the site in engineered fill placed in the late 1960s. Cracks ran generally parallel to the slope along virtually the entire eastern boundary of the site; most were less than an inch wide, but there were some up to three inches wide with six inches of offset. Offsets of up to six inches were also observed around structures located in the eastern portion of the site. Cracking continued to develop during aftershocks.

Many modern fills designed to current code were permanently deformed by the earthquake, causing severe damage to structures. Cracking of residential fills and related damage were observed at many sites in strongly shaken regions such as Valencia and Santa Clarita. Cracking was particularly evident in cut-and-fill transitions and where shallow fill was compacted on overcut areas. Little damage was observed where a deeper fill of uniform depth was placed on cut benches or where alluvial soils were removed prior to placement of fill.

Figure 13. Schematic of typical "wedge" fill geometry.



Earthquake Engineering Research Center, 1994

When fills are properly designed and constructed, they will resist earthquakes. Chapter 70 of the Uniform Building Code sets forth minimum rules and regulations to control excavation, grading, and earthwork construction. However, enforcement of good design and construction practices is not always consistent. Improved quality control measures will improve the performance of fills.

Recommendations

The Commission recommends that:

- State and local jurisdictions enforce provisions in Appendix Chapter 70 of the 1991 Uniform Building Code (Appendix Chapter 33 of the 1994 Uniform Building Code) as a minimum code for excavations and fills.
- Fills intended to support structures be designed and inspected by qualified professionals to ensure conformance with the current code and engineering practice; qualified technicians with proper certification inspect construction; the engineer of record certify that fill placement is in conformance with plan design; and when the fill is to be placed on bedrock, an engineering geologist inspect the geologic conditions before placement.
- Seismically induced deformations caused by seismic compaction of fill and underlying alluvium be considered in the design and construction of residential fills.

Continuing Education of Geosciences Professionals

Reduction of risk from seismically induced landslides, liquefaction, the failure of engineered fills, and other geologic hazards depends on the quality and skill of the professionals who must be capable of identifying and mitigating these hazards. After every earthquake, new knowledge is gained on how and why these hazards occur, their effects on structures, and the most cost-effective methods to mitigate damage. Professionals must be aware of advances in the state-of-the-art within their fields of expertise to remain competent. Continuing education is one way professionals can keep up with not only scientific advances but changes in law, land use planning, technology transfer, and other related subject areas. A strong continuing education program for practicing professionals would lead to improved professional practice and help reduce earthquake losses.

Recommendation

The Commission recommends that:

- The Department of Consumer Affairs' licensing renewal process require continuing education for geologists, geophysicists, engineering geologists, and geotechnical engineers.
- Licensing boards for geologists, engineers, and architects be required to hold hearings after each earthquake in the affected area to learn how their requirements can be improved.

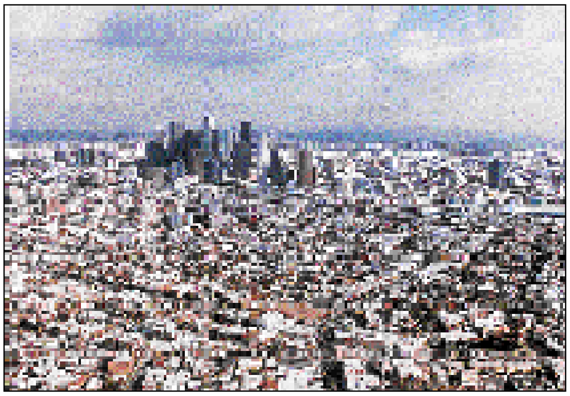
CHAPTER III

Achieving Seismic Safety in Buildings

California has many of the world's best earthquake safety experts and one of the most comprehensive building codes for earthquake resistance. Although these building codes and practices are generally adequate to protect lives, the Northridge earthquake demonstrated that they fall far short of what is needed to protect Californians from the economic disasters that major earthquakes cause. The unprecedented economic losses indicate that California still needs to make major improvements in building safety.

Los Angeles Times

A man peers into a collapsed parking structure.



A. Johnson

Figure 14. The Los Angeles region has over 8 million people in 3 million buildings, 240,000 of which were in regions of strong shaking during the Northridge earthquake.

The Northridge earthquake exposed a large urban building stock to intense shaking for the first time in California since the advent of modern building codes.

The Northridge earthquake exposed a large urban building stock to intense shaking for the first time in California since the advent of modern building codes. It lasted only about nine seconds, and much of its energy was directed at the rural Santa Susana Mountains; nevertheless, it vividly demonstrated that, although California has come a long way since the 1971 San Fernando earthquake, there are many improvements that still must be made to ensure that California's economy, as well as its citizens, can survive major urban earthquakes:

- *The quality of design and construction must be improved.* Poor quality in design, plan review, inspection, and construction were encountered over and over in the buildings damaged by the earthquake. California's current system of building design and construction encourages individual gambles that add up to significant risks, both for those who own the buildings and for those who depend on them as employees, tenants, or customers. Improving the quality of new buildings and making sure that remodeled buildings are seismically resistant will increase safety dramatically at a relatively minor increase in building costs.
- *Building codes must be improved.* Damage was expected and more prevalent in older buildings built to earlier codes. Modern buildings, in general, met the intended life safety level of the building code. Notable exceptions to this included poor performance in modern parking structures, tilt-up buildings, and welded-steel moment-frame buildings. Code changes have been proposed to begin to address these and other aspects for future construction. Future codes and seismic design guidelines should take better account of geologic and near-source effects on structures. In light of the extensive, albeit non-life-threatening, damage to modern buildings, the state should more actively support efforts to develop future codes, establish acceptable levels of earthquake risk in buildings, and develop design guidelines for meeting seismic performance objectives.
- *Nonstructural hazards must be reduced.* A building's heating and air conditioning systems, lighting fixtures, fire sprinklers, furniture, and equipment can become hazards in an earthquake if they are not adequately secured, and their loss can make a building unusable as surely as its collapse. Securing nonstructural elements is a relatively inexpensive way of improving seismic safety that can be applied to both new and existing buildings.
- *The risk from existing buildings must be reduced.* Improvements in codes and quality requirements for design and construction of new buildings will not reduce the risk posed by existing structures, and Northridge showed once again that older buildings are the most susceptible to damage in an earthquake. As a group, they pose California's single highest earthquake risk. The investment in these buildings is enormous; they cannot be replaced or retrofitted overnight, or for decades to come. However, local government programs can reduce this risk through zoning incentives and land use planning and by establishing triggers, such as significant remodeling projects, to require seismic upgrading.

General recommendations for achieving these goals are found at the end of the first sections of this chapter. Later parts of the chapter have specific recommendations for improving the seismic safety of several types of buildings that were damaged in the earthquake.

Improving Quality in Design and Construction

Damage resulting from a lack of quality showed up in all types of structures, from low-cost to very expensive single-family dwellings through multifamily apartment complexes to commercial buildings and highrise office buildings. Structures made of wood, steel, and concrete were all affected. A careful review of the damage has made it is clear that a significant portion of the damage was caused by one or more of the following:

- Inadequate engineering
- Inadequate design reviews
- Lack of understanding of the building code
- Misguided or incorrect construction practices
- Inadequate inspection or observation of construction

The greatest opportunity to ensure seismic safety is during a building's design and construction. The cost of ensuring quality is remarkably low—typically less than 2 percent of the cost of construction. The Northridge and other earthquakes have clearly and repeatedly demonstrated the remarkable effectiveness of paying attention to quality in reducing earthquake losses. Quality assurance is the single most important policy improvement needed to manage California's earthquake risk.

Though building code deficiencies may play a role in earthquake damage to some structures, a lack of quality at one or more points in the design and construction process is far more likely to be the primary culprit. As one experienced observer of the Northridge earthquake noted, in reference to damage of small wood-frame structures:

> Observation of the damages/losses suggests that good quality design, good plan check (review), good construction practices, good adherence to at least minimum or above codes, and good quality inspection by both private industry and local government would have reduced losses by a very high percentage. It appears that the low bidder caused more damage than the size or magnitude of the earthquake (Slosson, 1994).

Seismic safety in engineered structures is provided by three basic functions: design, construction, and oversight of these activities. The design responsibility typically falls to a professional—an architect or a civil or structural engineer. Construction is typically under the control of a general contractor. The oversight function that ensures seismic safety is carried out by government code enforcement agencies through plan checks and inspections and, in some cases, through the periodic observation of construction by design professionals.

California's current system of building design and construction encourages individual gambles that add up to significant risks.

In almost any human endeavor, one or more of three basic causes can be found to be responsible for a lack of quality:

- Limited money
- Limited knowledge
- Human error or carelessness

The vast majority of professional observers pointed to a lack of thoroughness, redundancy, and care as the primary cause of the unacceptable level of damage and financial loss. Many of these quality problems in the Northridge earthquake appear to have been financially driven. Continued economic pressures to lower design and construction costs have eroded the quality of both design and construction. Low-cost projects, which include both low-cost designs and minimum-quality materials, were present in significant failures in the Northridge earthquake.

Many owners who have only short-term interests in their buildings often opt for low-quality construction. However, each local government, and to an even greater extent state government, is adversely affected by the long-term, cumulative impact of these decisions, especially when earthquakes occur. The economic threat to California posed by future major earthquakes has arguably grown to become the single greatest threat to the state's competitiveness in the world market.

The lack of quality in construction is of concern in both new buildings and retrofit projects. Regarding damage to some retrofitted unreinforced

masonry (URM) buildings, the City of Los Angeles' Department of Building and Safety's URM Task Force reported that much of the damage appeared to be caused by errors in design or plan checking and lack of adequate quality control.

Design Deficiencies

Quality assurance is the single most important policy improvement needed to manage California's earthquake risk.

The Northridge earthquake exposed numerous indications of minimal or inadequate design practices that were commonly associated with damage. For example, the Los Angeles URM Task Force indicated a number of common design deficiencies in URM retrofits, including erroneous design assumptions, missing wall anchors, and inadequate anchorage in new shotcrete walls. Closer attention to critical design considerations would have reduced or prevented damage on several other types of retrofitted buildings as well.

Newer buildings that were severely damaged also showed significant design deficiencies and poor engineering judgment. For example, tall, narrow plywood walls had oversized connections that were intended to keep the walls from rocking,

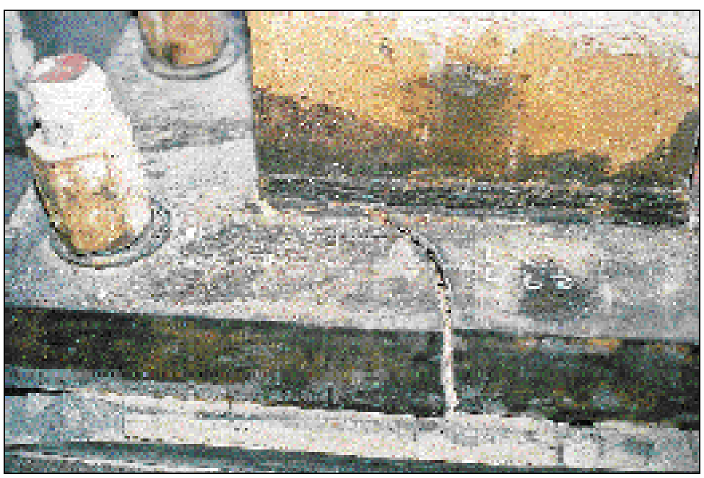


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Figure 15. A 4-inch-thick steel plate supporting the base of a column at the Oviatt Library at CSU Northridge. The plate fractured when the building was violently shaken.

indicating a basic lack of understanding of seismic design principles. Wider walls with more compatible proportions and smaller connections in other nearby buildings had very little damage. Similar design deficiencies were observed at a state-owned university building (Figure 15), which had very thick base plates and large anchor bolts to attempt to compensate for the small number of braced steel frames used.

Damage to tilt-up structures also indicated inadequacies in design. Inadequate reinforcing around anchors embedded in the tops of walls and pilasters is an example of poor design practice that contributed to damage. Faulty assumptions of lateral force distribution in calculations of out-of-plane support requirements may have also contributed to damage. Large gaps between wood roof members that were not considered in design but are present in hastily built, poor-quality construction were also identified as contributors to tilt-up failures.

An appropriate role for a designer is to provide an economical structure for the client. However, pursuit of low costs can evoke a classic conundrum of building design: inadequate, cheap designs drive out good but more expensive ones. The cheaper designs follow the letter of the code rather than its intent and often do not consider the structure's ultimate seismic performance. Engineers who design the least expensive structures are often rewarded with more work, producing even more pressure to minimize the structural elements. In these situations, the code, intended to be *minimum* requirements, instead becomes the *maximum* level to which buildings are designed. In highly repetitive construction, such as URM building retrofits, tilt-ups, and parking structures, the designs are refined many times, with the most inexpensive details reused—even if these details happen to be inferior (see Figure 16).

Overemphasis on low costs will also reduce the number of hours spent on important aspects of design such as developing alternate schemes and reviewing completed work. The drive for lower costs encourages repeated use of calculations and standard details, some of which may be inherently inadequate or not appropriate for all conditions. To reduce costs, engineers may simply leave drawings incomplete, change the design scope to include only a part of the structure (portions of some "designed" wood-frame buildings are built using only the rules of conventional construction) or leave parts of the structure to be "predesigned" or designed by contractors or suppliers (for example, wood and steel trusses, post-tensioned slabs, precast elements). The coordina-

tion of the final structure, particularly the lateral force path, can suffer in such cases, and the engineer of record may be difficult to identify (Adelman, 1994).

The pressure for more economical structures also encourages the use of design-build procedures, in which the contractor bids on both the design and the construction of the structure as a package. Since engineers and architects in design-build teams are working for the contractor, who must generally submit the low bid to get the job, they can be influenced to place a premium on economy and hasty construction techniques. The desire to survive in the highly competitive, often cutthroat, building industry can compromise the integrity and seismic safety of structures. Many professionals believe that design-builds can foster a conflict of interest for designers; at best, they create additional pressures to achieve the most economical design; at worst, they can produce poor construction and collapse-risk buildings.

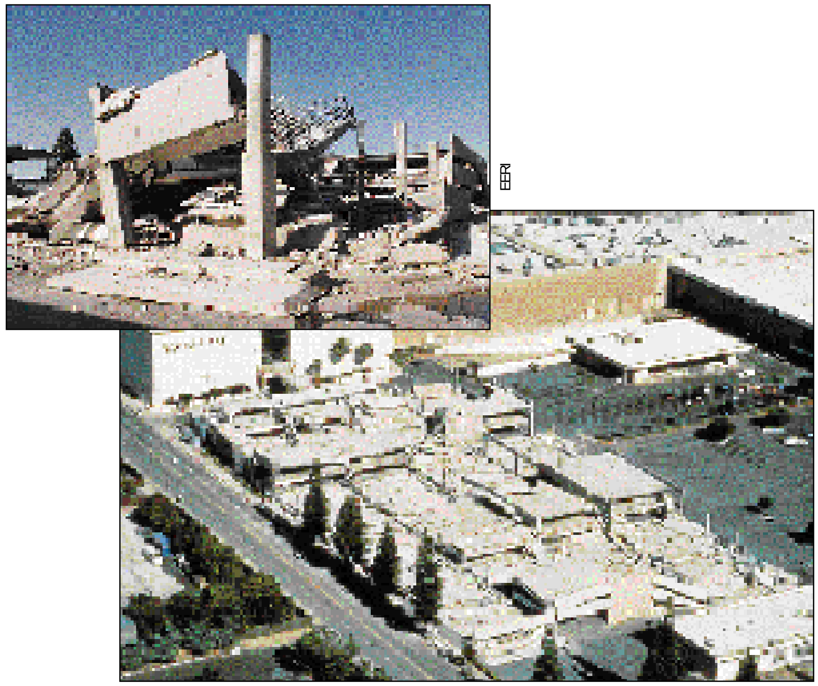
Construction Deficiencies

The best design can be negated by poor construction, and earthquakes have a knack for exposing construction oversights. Poor quality and lack of attention to construction details played an important role in Northridge earthquake damage. There was some concern even before the Northridge earthquake that box nails were being used in the field where common nails were specified. Box nails (see Figure 17) are the same length as common nails, but their diameter is smaller, so they are less expensive and easier to drive but they are not as strong. So using box nails instead of common nails to construct a plywood diaphragm or wall reduces its strength substantially. Following investigations after the earthquake, the City of Los Angeles directed that the allowable capacity of nails in plywood diaphragms and walls must be reduced unless special inspection is provided to ensure that common nails are used and properly installed.

Another quality concern was the application of stucco. Many of the stucco walls that failed were constructed by stapling wire mesh to wood-frame walls and applying the stucco over the mesh. The staples provided little earthquake resistance, and they held the mesh so tightly to the wall that the mesh did not become embedded in the stucco. Entire panels sheared off the wall when staples failed; even when they held, the initiation of cracking led to rapid disintegration of the stucco, which was unreinforced because the wire mesh was not adequately embedded.

Construction errors also contributed to damage in plywood walls. These errors included misplaced and bent anchor bolts; anchor bolts placed too close to the edge of concrete so they pulled out; bolt holes in sill plates drilled larger than necessary contributing to sill plates' splitting and sliding on the foundation; and wood framing members that were severely notched or had large holes cut through them to run pipes and wires without regard to structural integrity.

Poor quality and carelessness also caused damage in reinforced masonry and concrete structures. Errors included missing grout that made reinforcing steel ineffective and reinforcing steel that was placed too close to the exte-



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Los Angeles Times

Figure 16. This shopping mall parking structure collapsed primarily because its parts were not connected to each other. *Inset,* close-up of the same parking structure, showing separation of components.

rior face of the concrete, causing the concrete to peel off.

Although the Uniform Building Code (UBC) contains requirements that prohibit this type of construction, code violations and dangerous construction will persist without better education, observation, and inspection.

Code Enforcement Deficiencies

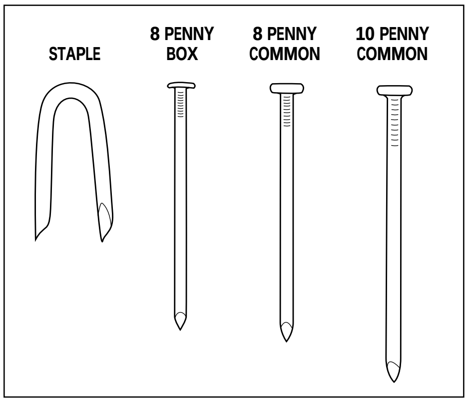

Figure 17. Smaller box nails and staples were routinely substituted for stronger common nails to reduce construction costs, also reducing earthquake resistance.

Inadequate quality of design or construction of buildings indicates that local governments' reviews of building plans or inspection of construction also was inadequate. Public school earthquake force requirements are the same as those for most apartment buildings, but public schools have fared far better in earthquakes. The primary reason for the superior structural performance of California's public schools compared to other, less regulated buildings is the detailed review of plans and calculations, particularly focused on the lateral force resisting system, and the formalized review and inspection of construction for schools. The structures that house the vast majority of our commercial infrastructure and people do not receive such attention. As a result, many of these buildings are not adequate to withstand shaking such as that experienced in the Northridge earthquake without extensive damage.

Improving Building Quality

Poor quality and lack of attention to construction details played an important role in Northridge earthquake damage.

The Commission believes the enhancement of quality in design and construction may be its most important single recommendation in response to Executive Order W-78-94. It is also one of the most problematic recommendations to define and measure in terms of effectiveness. However, unless quality is improved in the entire design-construction-inspection chain, efforts in other areas, such as code improvements, will be for naught. Policy makers, state and local government officials, owners, design professionals, and contractors must realize their shared responsibilities for seismic safety. Improving quality requires increasing accountability among owners, designers, and contractors.

Owners' Responsibilities

Building owners are typically not aware that they are primarily responsible for ensuring the quality of their construction. They are also responsible for the life safety aspects of their buildings both during and after construction. All too often, owners choose to be penny-wise and pound-foolish. Skimping on quality and seismic safety may save a few percent of the initial construction cost, but a damaging earthquake may devastate the real estate investment.

Owners must recognize that, though it is impossible to prevent all damage, they may be liable for failure to take reasonable measures to prevent injuries to employees, tenants, and customers. They should be made aware of their responsibilities so they can demand appropriate design and construction from the professionals who design and build their projects.

Quite often owners are faced with major earthquake losses because they didn't recognize the consequences of falling and damaged building contents. Contents should be installed to resist shaking and building distortion during earthquakes.

Recommendations

The Commission recommends that:

- Appropriate state agencies develop a strategy to make owners aware that:
  - They are responsible for seeing that reasonable and appropriate care is taken to hire qualified designers, inspectors, independent reviewers, and contractors and for clearly delineating the lines of responsibility for their functions in appropriate contract documents.
  - The building system with the lowest initial construction cost may actually have a shorter useful life and be significantly less resistant to earthquakes than

a slightly more expensive system or a building of higher quality.

- They are responsible for taking reasonable and appropriate precautions to protect building contents.

- Legislation be enacted to direct CalOSHA to adopt standards for bracing building contents and to promulgate and enforce regulations to require employers to include this information in their workplace safety and emergency plans.

Designers' Responsibilities

When a designer accepts a contract to design a building, the designer accepts a life safety trust from the people of the State of California. However, accountability for fulfilling that trust is practically nonexistent. State law must make it explicit that all designs that involve safety must have a clear line of responsibility for quality control from design through construction.

At present, there are a number of loopholes in this responsibility linkage. First, many designs include elements that are to be designed by the contractor. Although this practice may be cost effective and can yield satisfactory results, only the professional who designed the building is in a position to determine the adequacy of the completed building. The Commission believes that a single line of responsibility is the only method of ensuring the total seismic performance of a building.

A second significant loophole occurs during construction, when the best possible set of eyes—those of the designer—are not part of the construction review process. For reasons of liability and sometimes the owner's unwillingness to pay for such review, the designer of a project may not make site visits to view critical stages of construction and determine whether they comply with the construction documents. The Commission believes that construction oversight by the designer is an essential element of quality assurance and that it is not consistently present in construction statewide.

Designers must be accountable not only for the design of individual buildings but also for staying up to date regarding the state-of-the-art in earthquake-resistant design. Moreover, they must practice only within their areas of expertise. The state's currently accepted practice is providing life safety; the state has an obligation to ensure that those professing to hold this design expertise are truly qualified.

Architects are primarily responsible for the seismic safety of architectural elements in buildings as well as the coordination of architectural, structural, civil, mechanical, and electrical systems. Failures commonly occur during earthquakes because different building systems are not adequately coordinated. For example, fire sprinkler heads are sheared off by swinging ceiling systems; vents fall because they are not attached to ceilings; pipes leak when partitions are racked; large window panes break because their frames are not designed to accommodate building movements; and columns shear when partitions keep them from bending (see Figure 18).

Civil and structural engineers are primarily responsible for structural building elements in major projects. Mechanical engineers are responsible for the seismic safety of heating, ventilating, and air conditioning systems. Electrical engineers must design and ensure the adequacy of the electrical systems. Because of the ever-growing complexity of modern buildings, the coordination and delegation of design and construction duties is a critical part of achieving seismic safety. But all too often, owners do not insist on a clear delineation of responsibilities, and seismic safety suffers.

Current laws permit buildings and their parts to be designed by a variety of disciplines, including architects and civil, structural, mechanical, and electrical engineers. These professionals should be required by registration law to maintain a level of competence in seismic design commensurate with their responsibilities for such designs. Professional registration laws need to be strengthened to ensure that those who are responsible for seismic design have the appropriate qualifications.

The structural engineering profession was established specifically to provide specialized expertise

The primary reason for the superior structural performance of California's public schools compared to other, less regulated buildings is the detailed review of plans and calculations.

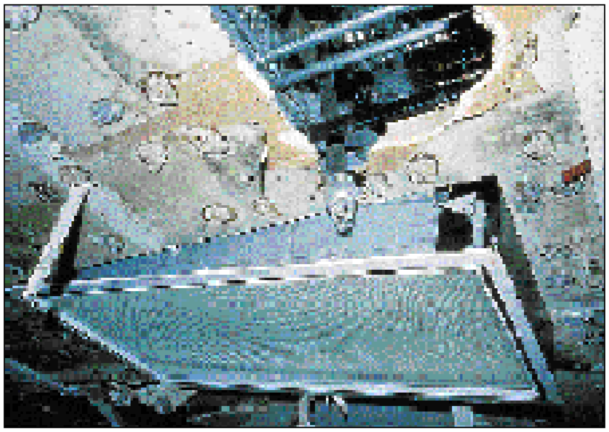

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Figure 18. When a ceiling panel (since removed) struck this sprinkler head during the earthquake, the pipe sprung a leak, causing extensive damage.

in seismic design. Currently there is no mandate in law or regulation that defines seismic design expertise, even though various agencies mandate the use of the structural engineering profession for certain types of critical structures. Moreover, there is no continuing education requirement that ensures maintenance of expertise in this area of rapidly evolving technology. The Commission believes that the expertise expected of the specialized field of structural engineering needs to be defined and that a program of continued education of that profession needs to be implemented and enforced.

Architects and civil, mechanical, and electrical engineers are not necessarily required to have formal education or work experience in the seismic safety of structures. In fact, it is still possible to graduate from most California colleges and universities in these professions with no formal coursework related to earthquakes. Many professionals receive their education and experience in other parts of the world and also have no formal education on earthquake safety. As a result, shoddy, marginal, and even incompetent designs are not uncommon. For these reasons, state regulations prohibit these professionals from practicing beyond their fields of demonstrated competence. However, few complaints regarding incompetence related to seismic design are filed with state licensing boards, and these regulations are rarely enforced.

Recommendations

The Commission recommends that:

- The California Building Standards Commission (CBSC) change the state's building standards to require that every building project have a single line of responsibility for the entire lateral force resisting system and vertical load carrying system assigned to the engineer or architect of record.
- CBSC amend the California Building Code to require designers of record to be responsible for a quality assurance program for structural and nonstructural elements for each project and, through personal knowledge, for the general compliance of construction with the contract documents.
- Legislation be enacted to hold designers harmless from claims, other than those claims specifically involved with observation of the work designed by the designer, when present at construction job sites.
- The Legislature periodically review licensing board activities to ensure that they are administering effective licensing examinations, requiring continuing education to maintain competency, and enforcing registration rules.
- The boards of registration for architects, engineers, and geologists hold hearings at the site of each damaging earthquake to determine the effectiveness of the boards in providing the necessary enforcement to ensure consumer protection and quality control over professional workmanship.
- The Board of Registration for Professional Engineers and Land Surveyors and the Board of Architectural Examiners raise the level of awareness of board rules that limit professional practice to areas of competency and the level of enforcement of those rules.
- Legislation be enacted to amend the title act for structural engineering to define the minimum level of seismic design expertise required of title holders.

Contractors' Responsibilities

The quality of the constructed product is greatly influenced by workmanship on the job site. The quality of construction can be improved when contractors and their workers understand the basic concept of earthquake-resistant construction: building elements that

are well connected with quality materials and details perform well in earthquakes.

The state's construction industry is generally well intentioned and would like to produce quality buildings. Greater awareness in the construction industry of basic principles of earthquake-resistant construction will result in fewer details that are hastily installed and fewer parts of buildings being omitted entirely. The state needs to establish and encourage methods to transfer basic knowledge to the construction industry—contractors, job supervisors, and workers—so that earthquake safety and the importance of quality in ensuring safety reaches a high level of awareness.

Recommendations

The Commission recommends that:

- Legislation be enacted to require the Contractor's State Licensing Board to test candidates for a working knowledge of practical seismic safety principles in their contracting disciplines as part of the normal examination process and to require continuing education to ensure that contractors maintain competency in this area.
- The Contractor's State Licensing Board hold hearings at the site of each damaging earthquake to determine the effectiveness of the board's efforts to ensure consumer protection and quality control.

Building Code Enforcement Agencies' Responsibilities

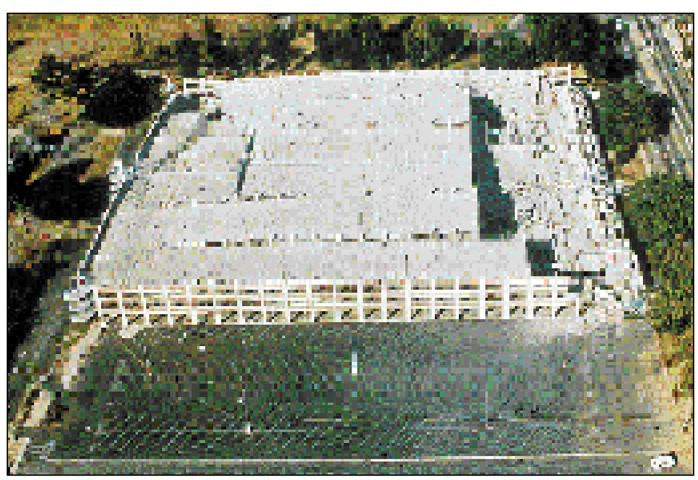
The public expects building departments that enforce the building code to protect against deficiencies in design and construction. However, these departments vary dramatically in size and expertise throughout the state. Many lack budgets and personnel to thoroughly and consistently carry out the state's Riley Act, which requires checking building plans, issuing building permits, inspecting construction, and issuing certificates of occupancy for all new construction.

Plan checkers and building inspectors are responsible for making sure that building designs meet both the letter and the intent of building code provisions and that construction is carried out in accordance with the plans and good construction practice. As a matter of policy, plan checkers and inspectors should also notify the owner and the appropriate professional registration board if they believe that a designer or contractor is incompetent or is deliberately failing to follow appropriate procedures. Unfortunately, there are no guidelines or minimum standards for the performance and qualifications of plan checkers or inspectors; in fact, a significant number of state and local government building code enforcement agencies do not have any licensed building professionals on their staffs. This vital aspect of the overall construction process needs support if the quality of construction is to be improved.

Although private building plans are checked and construction inspected by local government plan checkers and inspectors who are independent of the building owner, the state and many local governments exempt their own building projects from such independent plan checking and inspection requirements. For example, the California State University (CSU) system, the University of California (UC) system, and the state Department of General Services do not have independent plan checking functions. Building failures such as the collapse of CSU Northridge's recently built parking structure in the Northridge earthquake and the collapse of the auditorium at CSU

Building elements that are well connected using quality materials and details perform well in earthquakes.

Figure 19. Constructed in 1991, this CSU Northridge parking structure collapsed when interior columns failed.



A. Johnson

Figure 20. Interior columns failed and girders fell off supports in this CSU Northridge parking structure.

Long Beach without an earthquake are symptoms indicating that independent and competent plan checking of such structures is needed. Since there is an inherent conflict of interest when plan checkers are hired by the managers responsible for completing buildings, they should be responsible to another level of government: state university buildings might be inspected by the Division of State Architect or a qualified local building department. The success of the truly independent Field Act plan check process for construction of public schools illustrates the importance of this factor (see figures 19 and 20).

The success of the Field Act in ensuring safe school buildings illustrates the importance of plan checking.

However, plan checking has practical limits. A designer can comply with the letter of the building code and still produce buildings that perform poorly because of the limitations of the code. This is particularly true for complex or irregular buildings that are often not included in the scope of the code. Building code enforcement agencies should be aware of these limitations of the code and require owners to engage peer reviewers starting at the early, conceptual stages of designs for important, irregular, or complex buildings. Peer review by independent design professionals with specific experience in unique building systems can ensure proper engineering judgment even though the code provides no direct guidance. Early intervention by peer reviewers is necessary to catch conceptual flaws that may be difficult, if not impossible, to address later. The typical cost of peer review, a small fraction of the cost of design, can pay off with enhanced, reliable seismic performance. As in medicine, a second opinion can save lives and reduce losses.

Recommendations

The Commission recommends that:

- Legislation be enacted to make structural plan checking of engineered buildings an act requiring professional licensing.
- CBSC amend the California Building Code to require all building code enforcement agencies to require owners of important, irregular, complex, or special-occupancy buildings to hire, as part of the permit process, independent peer reviewers whose involvement starts with schematic design phases and continues through construction.
- Legislation be enacted to require building inspectors and public and private plan checkers to be trained and certified by nationally recognized organizations and subject to continuing education requirements by recognized organizations in their areas of competence. Inspectors and plan checkers should be restricted from inspecting and checking plans beyond their areas of certification and competency.
- CBSC amplify what is already allowed by state law and amend the California Building Code to empower building departments to reject incomplete plans and collect additional fees for reconsideration of incomplete plans. Building code enforcement agencies should file complaints against designers and contractors who violate the building code or approved construction documents, and such complaints should receive priority over other complaints.
- CBSC—with the assistance of boards of professional registration, the Contractor's State Licensing Board, and inspection and plan check certification organizations—develop a standard method for filing complaints on repeat code violators and preparers of incomplete plans.

- Building code enforcement officials and professional associations work together to develop timely changes to the UBC and California amendments to the code to incorporate the changes recommended above.
- Legislation be enacted to require all state, local, and special agencies, including UC and CSU, to have a formal and independent building code enforcement entity with clear and appropriate enforcement, citation, and stop-work responsibilities and authority.

Improving Building Codes

At the heart of Governor Wilson's executive order is the question "Is the building code safe enough for earthquakes?" With few notable exceptions, the UBC provides an adequate level of life safety for new construction as long as the code is strictly applied during the design and construction of buildings and as long as the code is enforced with thorough plan reviews and inspection. As long as the current performance objectives are acceptable, the building code itself is not in need of a major overhaul, but far more attention to strict adherence to the code and the elimination of shoddy design and construction is clearly needed for earthquake-safe buildings. Recent changes to the earthquake requirements in the building code have not been adequately substantiated and do need to be more comprehensively verified in the future.

Since before the 1906 San Francisco earthquake, seismic design engineers have been developing building codes to achieve the goal of protecting lives by preventing structural collapse or massive wall failures. Revisions and refinement of California's seismic code provisions have traditionally been based on engineering research and observations of building damage—each significant earthquake has made its contribution to improving building safety.

The Northridge earthquake provided the first significant test of modern building codes. It indicated that, in general, buildings built to current codes achieve life safety performance if the codes are strictly applied during design and construction and enforced with thorough plan reviews and inspection. Most building owners did not anticipate the extent of damage that occurred in the Northridge earthquake. In the majority of cases the code's seismic performance objective of life safety was met. However, the Northridge earthquake caused structural and nonstructural damage to buildings far exceeding the expectations of owners and occupants of most of the damaged buildings. The financial losses from this earthquake were high for individual building owners, tenants, the real estate market in general, businesses such as insurance companies and lending institutions, local governments, and state and federal agencies. Improved performance can be accomplished by increased attention to quality in design and construction, better minimum standards and code rationale, and better code enforcement with only slight increases in cost.

As in medicine, a second opinion can save lives and reduce losses.

There were troubling exceptions to the performance of modern buildings in the Northridge earthquake: steel-frame and tilt-up buildings, above-grade concrete parking structures, and buildings located in areas that experienced violent ground motion did not perform to expectations.

Therefore, though modern construction generally fared well, some changes to the code development process are needed:

- Building materials, their connections, and code requirements must be more thoroughly substantiated with testing and independent evaluations.
- Major buildings situated near active faults or known geologic features should be designed to accommodate their unique effects on ground shaking.

Improving the codes themselves requires several steps:

- Improving accountability for codes.
- Establishing clear public policy on acceptable performance objectives.
- Supporting the monitoring, testing, research, and knowledge transfer needed to meet the desired objectives.

MODERN BUILDING CODES

For engineered structures, modern building codes—or at least their seismic, or lateral force, provisions—are generally considered to be the 1976 and later editions of the UBC. For conventional construction, which includes most single-family residences, codes that are considered equivalent to modern go as far back as 1949, depending on when the local jurisdiction adopted certain provisions such as requirements for foundation anchor bolts.

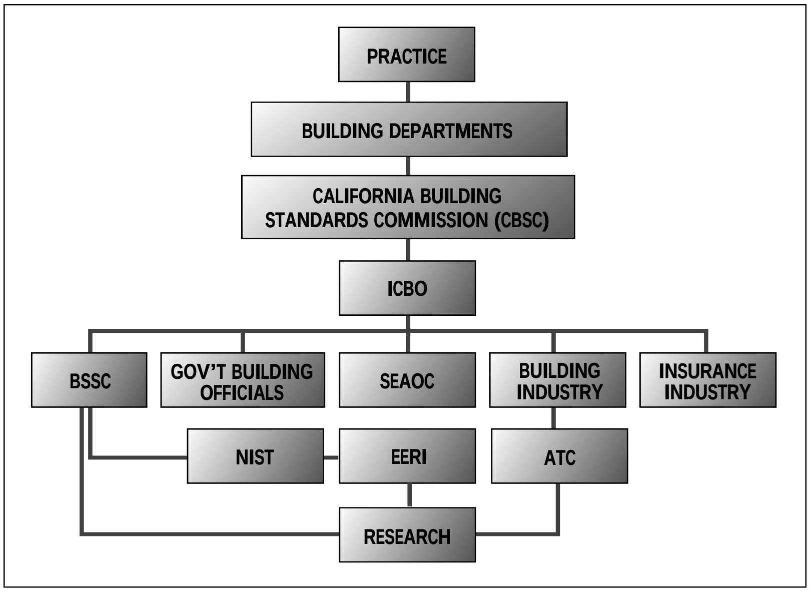


Figure 21. The building code development process for seismic safety is complex. It involves many organizations and steps, but no one is clearly responsible or accountable for its overall adequacy.

How Building Codes Are Developed and Administered

Californians rely on building codes as their foremost line of defense against the vulnerabilities of buildings. Codes cover all aspects of building design and construction, from seismic design requirements to heating, electrical, and plumbing specifications and down to details such as the proper type of nails. They regulate the work of owners, architects, designers, engineers, contractors, crafts workers, and others in the construction of habitable buildings.

Building codes were initially straightforward requirements for relatively simple buildings. The building code of 50 years ago was a single volume a few hundred pages long. Today, the codes used in California come in several volumes and are thousands of pages in length. Over the years, significant additions and changes have been made to address newly acquired knowledge and other considerations ranging from new types of materials and buildings to seismic concerns, as well as constantly changing laws and regulations governing design and construction of special buildings such as hospitals, schools, and essential services buildings. Many engineers believe this complexity leads to misunderstanding of design concepts and to the mistaken impression that following the code guarantees good performance.

California's building codes are based on the Uniform Building Code (UBC). Though the UBC is adopted, and sometimes modified, by local jurisdictions, state law sets minimum code standards that in only some cases are higher than the UBC's; for example, the state sets special provisions for hospitals, essential services facilities, and private and public schools.

The UBC is maintained and published by the International Conference of Building Officials (ICBO), but several other groups also contribute to its seismic safety development (Figure 21):

The International Conference of Building Officials is a private, nonprofit organization with state and local government building officials from the midwest and western United States as its voting members. ICBO publishes, maintains, and promotes the use of the UBC and its companion codes and standards. ICBO provides an evaluation service to ensure the seismic safety of a myriad of proprietary building products, connections, materials and other systems. ICBO also provides continuing education products, services, and administrative guidelines to its members.

Structural Engineers Association of California (SEAOC) has been involved in the development of seismic codes since the 1940s. Historically, ICBO has adopted the provisions of the SEAOC "Blue Book" for the UBC's seismic provisions. SEAOC's Seismology Committee spends thousands of volunteer hours per year on its main task of interpreting and updating of the "Blue Book," with travel costs and administrative and publishing support coming from SEAOC dues. Since its inception, the "Blue Book" has had two major revisions: the 1973 edition, which incorporated changes developed in response to the 1971 San Fernando earthquake and a 1988 rewrite that changed the basic format to better agree with ATC 3-06, which is described below.

Applied Technology Council (ATC) was established in 1971 to expand SEAOC's efforts in code development and technology transfer beyond what was possible with only volunteer efforts. ATC's first major project was ATC 3-06, *Tentative Provisions for the Development of Seismic Regu-*

lations for Buildings, which was intended to develop the basis for a completely new national seismic code. The document advanced the state-of-the-art considerably and developed a new format for seismic provisions, though buildings designed using these provisions were not much different from those designed using the practices adopted as a result of the 1971 San Fernando earthquake. Now nationally oriented, ATC organizes and implements research, code development, and technology transfer projects with funding from several sources including the National Science Foundation, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey, and the State of California.

Building Seismic Safety Council (BSSC) was established in 1979 as an independent, voluntary body under the auspices of the National Institute of Building Sciences (NIBS) as a direct result of federal interest in the seismic safety of buildings. Its primary role with respect to codes has been publishing updates to ATC 3-06, now called *National Earthquake Hazard Reduction Program Recommended Provisions for the Development of Seismic Regulations for New Buildings,* and assistance with its implementation. Revisions of the NEHRP provisions are done by committees as volunteers, as in the case of the "Blue Book," but on a national level. Travel and administration costs are funded by NIBS. Two competing seismic codes are now in use in this country—one based on SEAOC's recommendations and one based on BSSC's NEHRP recommendations.

California Building Standards Commission (CBSC) was established in 1979 to encourage uniformity in California's building codes and to minimize state-mandated changes to the UBC. The CBSC requires state agencies to justify all proposed amendments to the UBC before they can be adopted. Four state agencies can amend the UBC for seismic safety purposes: the CBSC, the Division of the State Architect (DSA), the Office of Statewide Health Planning and Development (OSHPD), and the Department of Housing and Community Development (HCD). State-approved amendments can be found in the California Building Code, which is published by the CBSC.

Improving Accountability in the Code Development Process

The administrative process for adopting changes to the building code works well in some respects; it is methodical, unbiased, and open to public scrutiny and participation. It can accommodate rapid code changes, as demonstrated by ICBO's recent emergency revisions to steel-frame building design requirements as a result of the Northridge earthquake, though it can take a decade or more for major changes to be incorporated into the code. However, it is a relatively obscure, technical, and bureaucratic process that is relegated to and dominated by interests with competing priorities and biases.

Though many organizations and individuals are active in the building code development and enforcement process, the state currently lacks a formal entity that can be held responsible for ensuring that appropriate reviews and policy changes are instituted, especially when questions arise regarding the adequacy of the building code after disasters. Accountability for building codes is now dispersed by a process that involves hundreds of volunteers and state and local building officials; as a result, key assumptions on which parts of the building codes rest are often accepted without adequate substantiation. This policy of benign neglect continues to place the state at a large and growing risk.

National materials manufacturers and vendors, who have a legitimate financial interest in gaining and maintaining approval for their products in the codes, fund and oversee the development of information regarding their own products. The public interest is represented by private-sector volunteer design professionals and interested public officials whose participation is "volunteered" by their agencies but is often carried out largely on their own time, on top of their other duties. Too little of their time is available to make major advances in codes and their underlying philosophy. As a result, the code development process for seismic provisions is fragmented, often slow, lacking in accountability, and highly dependent on the availability of an informal network of volunteers. The coordination

The economic threat to California posed by future major earthquakes has arguably grown to become the single greatest threat to the state's competitiveness in the world market.


Tobin

Figure 22. This industrial tilt-up building had its roof and wall partially collapse.

and integration of all these interests into a consistent, economical code procedure that provides an "acceptable" level of seismic performance has become extremely complex and may be beyond the capacity of the current processes.

Because seismic hazards are a national concern, participation in code matters involves seismic professionals and government officials from across the country, and the committees and meeting venues must reflect these geographic interests. Californians clearly have a far greater interest in the seismic provisions of the codes than other states, but that interest is only a part of the equation. Code change proposals and challenges to California proposals now come from many organizations and individuals other than California's structural engineers and building officials. So the code remains a compromise, and not all of what California needs is adopted.

The Northridge earthquake demonstrated a few notable shortcomings in the way in which technical changes to the building code are developed and verified. Recent changes in the code have not always been substantiated by comprehensive building materials testing and applied technology. As a result, billions of dollars of real estate investments now rely on unsubstantiated and, in some cases, potentially unreliable seismic safety requirements. Two examples illustrate this breakdown in the system of incorporating technical changes to the building code:

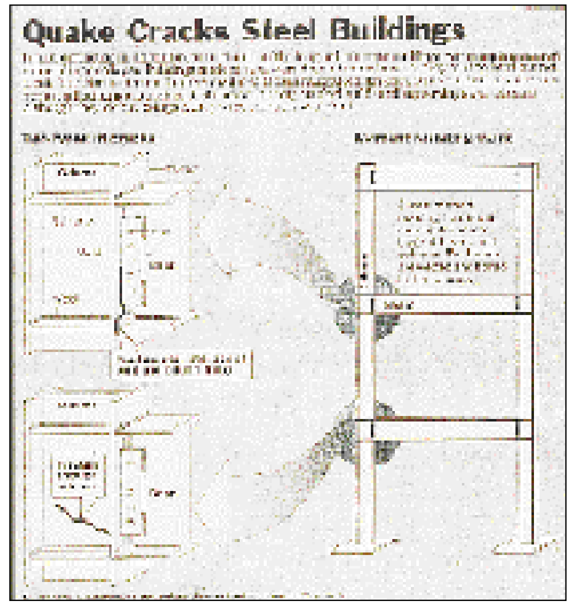
- The 1971 San Fernando earthquake showed that most tilt-up concrete buildings had an inherent weakness in the connections between the walls, roof, and floors. These connections failed, causing roofs to partially collapse and walls to fall away from buildings. Changes were made in the 1973 and 1976 editions of the building code that required wall-to-roof connections to be designed for higher forces and added new measures to avoid the premature splitting of wood members, but no substantiating tests to verify the new code requirements were ever carried out. The changes neglected to consider the flexibility of connections and the effects of their resulting displacements and overlooked the modes and sequences of response of the wall-to-roof connections as buildings move in response to ground motion. As a result, modern tilt-up buildings did not perform much better in the Northridge earthquake than pre-1973 tilt-ups. For an additional 20-plus years, tilt-up buildings have been built with less-than-reliable wall-to-roof connections (Figure 22).
- There were many failures of welded-steel moment-frame joints in the Northridge earthquake. The building codes allowed major investments in this type of construction although, in hindsight, there has clearly been a lack of substantiating research to verify the adequacy and reliability of welded-steel moment-frame joints. The code changes in the 1960s that allowed these fully welded steel frames were based on small-scale tests of steel beams that were on the order of ten times lighter and one-fourth the depth of beams now in wide use. Minor investments in full-scale tests back in the 1960s could have saved the industry from billions of dollars in Northridge earthquake losses alone. Had there been strictly enforced testing criteria for the acceptance and verification of building code changes, the problems with steel-frame joints could have been avoided (figures 23 and 24).

The code has become so complex that additional reliability and higher seismic performance cannot be achieved by simply increasing code requirements or making designs more conservative. This is best exemplified by current hospital design and construction requirements. Significant enhancements in hospital seismic performance were achieved primarily by improving quality control through rigorous plan checking and inspection. Though hospital seismic force requirements were arbitrarily increased by 50 percent, there is little evidence that this increase significantly enhanced seismic performance. The failures of nonstructural systems in hospitals indicate that their damage was due more to a lack of coordination in installing complex systems than to inadequate seismic force requirements in the code.

The complexity of the building code also makes it difficult for average building design professionals to keep up to date on the latest seismic provisions and the theories underlying them. It will do the state no good to improve the building code without commensurate improvements in the quality and competency of designers, contractors, and building code enforcers.

An additional problem is that in some cases, there is less profit in compliance with the intent of the code than there is in finding loopholes in it. In this game, those who charge small fees to design and build low-cost, low-quality buildings are the winners, rewarded with more work, so the minimum code requirements become the de facto maximum. The losers are those who may lose their lives, health, or economic well-being when a structure does not perform as expected. The Commission is not so naive as to believe that a new approach to seismic provisions in the code will entirely solve this societal problem, but present provisions make evasion of the code's intent too easy.

The fundamental approach for seismic design was set in the codes before development of our present-day knowledge regarding the nature of shaking and the response of structures to that motion. For the vast majority of buildings, it works quite well. Continuous improvements in the strength or capacity of buildings to withstand motions have been made as needed. The use of traditional elastic design techniques, in which the actual nonlinear response of the structure is not well represented, has also required continual adjustments to the code. During development of lateral force provisions in the 1980s, it was concluded that the expected shaking should be specified more precisely, and concepts such as peak ground acceleration, effective peak ground acceleration, and design response spectra were introduced into practice. However, this has not changed the code's original primary focus, which has been on design for adequate overall capacity in broad regional earthquake zones to maintain life safety. It would be difficult to accommodate unusual cases of structural dynamic irregularities, or the potential for unusual shaking, in the current code format without expensive penalties to all buildings.



Los Angeles Times

Figure 23. Though no steel-frame buildings collapsed, cracks in connections have stimulated efforts to substantiate building code requirements.

Recommendations

The Commission recommends that:

- Legislation be enacted to designate CBSC as the entity responsible for the adequacy of the seismic safety codes and standards for all buildings in California. CBSC should ensure that building codes and their administration meet the state's acceptable levels of seismic risk through various actions, including but not limited to:

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Figure 24. Cracks in slightly damaged steel buildings were often undetected until months after the earthquake.

  - Ensuring the adequacy of existing and future seismic safety requirements in the model codes and state amendments.
  - Developing and adopting new seismic safety requirements for amendments to the building code for statewide applications.
- Legislation be enacted to authorize CBSC to establish a task force including other affected and interested agencies and organizations to develop plans to fulfill this responsibility within one year of the above legislation.

Higher seismic performance cannot be achieved by simply increasing code requirements.

Simplified code provisions for most simple buildings should require minimal interpretation skills and reflect the educational background and seismic awareness of average design professionals and code enforcers. The CBSC should also consider establishing comprehensive guidelines that go beyond the code and can be referenced in future codes for special occupancy buildings, essential services buildings, complex or irregular buildings, and buildings on unusual sites by the year 2000. These guidelines are needed for those few buildings in California's building stock that demand and deserve refinements above and beyond simple, prescriptive building code requirements. The guidelines should:

- Emphasize a variety of earthquake performance objectives so that owners and designers can explore options and select from a variety of approaches and systems to achieve desired levels of seismic risk.
- Define materials testing and building system verification and reliability requirements.
- Give parameters for design and analysis of building systems that reflect realistic earthquake ground motions, response, damage limit states, variability, and uncertainty of building systems.
- Outline procedures for independent reviews, quality assurance, interpretations, and enforcement procedures required for their appropriate application.

Building Code Performance Objectives

Observations from the Northridge earthquake have led the Commission to conclude that the time has come to add new tools to current procedures to design and build earthquake-resistant structures in California and to introduce responsibility and accountability into the process of code development. A new seismic design methodology is needed that more directly considers our current knowledge of ground motion and nonlinear structural behavior and that will better predict levels of performance and damage. The present codes do not provide for multiple performance objectives that would allow building owners, architects, engineers, and the financial community to make more informed—and therefore, perhaps, better—decisions regarding the performance of structures in the event of an earthquake.

Following the Northridge earthquake, public attention was on loss of life, high-profile structural failures, and enormous economic losses. Even though the vast majority of buildings did not collapse, there was a perception that overall building performance was unacceptable and that building codes and the construction process may not be adequate. The stated purpose of the Unified Building Code is potentially misleading to the public:

> The purpose of this code is to provide minimum standards to safeguard life or limb, health, property and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein.

The general public is not aware that the intended performance objectives of today's building codes permit—even expect—substantial damage from strong shaking. Most believe that buildings constructed to modern codes, as well as retrofitted buildings, would not be significantly damaged in events such as the Northridge earthquake.

The intent of the current seismic provisions of the UBC, as described in the SEAOC "Blue Book" commentary, is that:

> Structures designed in conformance with these Recommendations should, in general, be able to:
>
> Resist a minor level of earthquake ground motion without damage;
>
> Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage;
>
> Resist a major level of earthquake ground motion having an intensity equal to the strongest either experienced or forecast for the building site, without collapse, but possibly with some structural as well as nonstructural damage (SEAOC, 1990).

The performance objectives implied (though not stated) in building codes have not materially changed over the years. Changes to the codes have been in the requirements felt necessary to meet those seismic goals. Modern codes have the same goals as the older codes, but buildings built to the older codes are generally more vulnerable because they were designed and constructed to less comprehensive seismic requirements. For example, reinforced concrete frame requirements in the code were enhanced dramatically in the 1976 edition of the UBC.

Did Buildings Meet the Code's Objectives?

A complicating factor in any discussion of how well building codes achieved their intended result in an earthquake is that any buildings being studied after a damaging earthquake like Northridge are the products of multiple building codes. The infinite variety of buildings have been designed, constructed, remodeled, renovated, and repaired over decades to different codes and are often a combination of different types and strengths of materials. Seismic considerations first appeared in California building codes in the early part of this century and the codes have been amended many times. Significant changes to seismic requirements occur in the codes following large damaging earthquakes (for example, the 1933 Long Beach and 1971 San Fernando earthquakes) in addition to regular code changes. It is also very difficult to know the intensity of shaking that individual buildings were subjected to in an earthquake. Although some structures are instrumented to gather such data, usually only educated estimates are available regarding the intensity of shaking that any given structure experienced.

Despite these complexities, the Northridge earthquake did provide a valuable test of seismic building codes. A large and varied inventory of structures was subjected to intense accelerations roughly comparable to seismic design assumptions of modern codes (post-1976). The amount of energy produced by the motion and transferred into the structures was large enough in many cases to push buildings beyond the point where damage began to occur. The energy in such a situation seeks out weaknesses and exposes poor quality or errors in design and construction.

To assess *current* seismic codes, the focus must be on the damage to modern, post-1976 buildings. A number of the structures that suffered spectacular collapses in the Northridge earthquake (for example, Bullocks, the Kaiser office building, and the Northridge Meadows apartment complex) were built to codes that predated the changes made following the 1971 San Fernando earthquake.

From the perspective of the code's primary objective of life safety, buildings built to post-1976 codes essentially met the intent of the code; no loss of life occurred as the result of structural failure of any modern-code building. However, the earthquake challenged the code's implied objective that buildings should generally resist "a major level of earthquake ground motion . . . without collapse, but possibly with some structural as well as nonstructural damage." At least two notable classes of buildings constructed under modern codes, concrete tilt-ups and steel moment frames, received considerably more than "*some s*tructural damage" and many other buildings that conformed with modern codes,

The best design can be negated by poor construction, and earthquakes have a knack for exposing construction oversights.

Figure 25. Though falling acoustic ceiling tiles like this are not particularly dangerous, falling light fixtures and other heavier elements can be.

though they may not have had severe structural damage, had more than "some nonstructural damage." In addition, parking structures, some built to modern codes, suffered severe collapses.

Moreover, a number of factors may serve to dampen any feelings of elation over the relatively few deaths that occurred:

To continue down this path of minor code changes makes the task of improving building seismic performance difficult, time consuming, expensive, and only marginally effective.

- Though the shaking in this earthquake was intense, it was the product of a moderate-magnitude, short-duration event. It is reasonable to assume that either a larger magnitude earthquake or one of similar strength but longer duration will subject similar structures to a substantially more strenuous test.
- A number of modern buildings suffered so much structural damage that, had people been in or near them at the time of the earthquake, there would undoubtedly have been much more loss of life. This was particularly true in the case of concrete-frame buildings, tilt-ups, and parking structures.
- Nonstructural hazards and building contents continue to pose a threat to life even in modern buildings (see Figure 25).

Seismic Performance Objectives Must Be Clarified

Continuing current practices that have performance goals aimed primarily at protecting life may no longer be appropriate for many building types. The state has a vested interest in the economic protection of the building stock to protect the state's economy and public welfare and to ensure that essential services continue to function after earthquakes.

Though various implied performance objectives or goals for specialized occupancies such as hospitals and essential services buildings set forth in separate laws, there are no clearly defined levels of seismic performance objectives in the current building code. Thus, there are no explicit choices for owners, lenders, insurers, or governmental agencies for more typical engineered buildings or for conventional wood-frame construction. Owners can choose to exceed minimum building code requirements, and engineers can encourage them to consider how slightly increased design and construction costs might reduce damage in future earthquakes, but comprehensive design guidelines to help owners and engineers evaluate these alternatives are not widely available. Such design guidelines are still in their developmental stages, so designs that exceed minimum building code requirements are now the exception rather than the norm. Most owners simply assume the code is good enough or the best that can be done.

Besides improved reliability in meeting the life safety minimum performance objective, many building owners and tenants need enhanced performance objectives that go beyond the life safety minimum to allow for reoccupancy of damaged buildings and resumption of building functions in a timely manner after future earthquakes as well as lower repair costs. Without a framework of widely accepted design guidelines that encourage higher seismic performance objectives, it will be extremely difficult to bring together the financial community, commercial building owners, building designers, and government to provide buildings that will remain functional and suffer less damage after future earthquakes.

The Commission believes the approach to seismic design used in the building code requires significant change. The code's seismic provisions are simplified for ease of enforcement and do not always reflect state-of-the-art knowledge about the dynamic behavior of buildings. The original performance goals and seismic

provisions of the code were developed many years ago when the understanding of earthquake shaking and building response was far less sophisticated; today, many of the original underlying assumptions of the code are no longer appropriate. Even though the code is amended after every earthquake, the fundamental approach has not changed. To continue down this path of minor code changes makes the task of improving building seismic performance difficult, time consuming, expensive, and only marginally effective.

Many believe there is a need for performance-based design guidelines in California. Without widespread use of performance objectives that encourage and promote reduction of damage from shaking, the financial risk from earthquakes will continue to increase. The Commission believes the policy of this state must be to encourage and facilitate an environment in which building owners, designers, lenders, insurers, and government (from local to federal) view seismic performance as critical to minimizing economic losses. The state should actively participate in the development of enhanced seismic performance objectives, incentives, and risk-sharing programs that will lead to risk reduction.

Seismic performance objectives for buildings can be raised if measures are taken that go beyond the code. Structures can be designed and constructed to withstand even more intense shaking than seen in the Northridge earthquake with less damage. The knowledge and ability exist, and the incremental cost for new structures is not prohibitive.

Achieving Performance Objectives

New seismic design guidelines can be developed that will achieve different building performance objectives under various levels of shaking. However, it is clearly not possible, and indeed may be dangerous, to attempt to place new seismic performance objectives directly into the existing building code. Instead, future codes should refer to a set of comprehensive design guidelines that offer owners and designers both the flexibility and the tools to meet performance objectives much more reliably than current codes.

Under such a concept, the seismic performance desired for a building could be specified from several available, ranging from a minimally acceptable objective that would ensure life safety, through intermediate objectives providing greater protection against damage, to an objective aimed at providing continuous occupancy and the functioning of essential services after design-level earthquakes. Owners might even be required to disclose seismic performance objectives to prospective buyers of buildings. The use of guidelines would rely heavily on engineering judgment and peer review to ensure that their applications are appropriate.

SEAOC, in its Vision 2000 project, and FEMA are both interested in developing guidelines that would achieve different performance objectives. Given the competing interests involved and the nature and history of code changes, it is reasonable to expect that such a change is not likely to occur until well into the twenty-first century without strong support from such entities as state and local governments and insurance and lending institutions.

There are difficult questions to be resolved, involving such issues as defining performance objectives, providing for variability of actual performance, and addressing owners' and professionals' liability issues and insurance. Perhaps the biggest hurdle is to find cost-effective ways to increase the reliability of building systems so that they will more consistently meet or exceed performance objectives. However, none of those problems are insolvable. The Commission believes that the process of developing more appropriate seismic provisions needs to be given more specific support and direction from government policy makers, owners and operators of essential services buildings, and lending, real estate, and insurance interests.

Without the development of widely used design guidelines for enhanced seismic performance objectives, it will be extremely difficult to develop a rational scheme of creating incentives for owners, lenders, insurance companies, and the government to promote and facilitate the design and construction of many different types of buildings

The first step in developing enhanced seismic performance objectives is to establish a clear policy on acceptable levels of risks.

that will sustain relatively nominal damage in a strong earthquake. Without recognizable and realizable alternatives for seismic performance, lenders, insurance companies, appraisers, and others cannot provide appropriate financial incentives. The Commission believes that now is the time for initiating a process to improve seismic performance objectives for buildings. It is in California's best interest to develop seismic provisions that not only protect public health but also the economic welfare of Californians.

Acceptable Seismic Risk

Buildings built to post-1976 codes essentially met the intent of the code. No loss of life occurred as the result of structural failure of any modern-code building.

Tradeoffs between earthquake risks and higher performance objectives boil down to the questions "How safe do we have to be, and how much are we willing to pay for it?" Bearing in mind that there is no absolute safety from earthquake risks and that payment for such safety as can be ensured is not only in money but in convenience, amenities, and competitiveness, the first step in developing enhanced seismic performance objectives is to establish, at the highest levels of government and the private sector, a clear policy on acceptable levels of earthquake risk. The Commission's *Policy on Acceptable Levels of Risk in State Government Buildings* is a good starting point:

> The goal of this policy is that all state government buildings shall withstand earthquakes to the extent that collapse is precluded, occupants can exit safely, and functions can be resumed or relocated in a timely manner consistent with the need for services after earthquakes. Compliance with this policy will provide reasonable protection of life, but it will not prevent all losses of life, building function, or damage.

The Commission believes that it should convene, with the Governor's assistance regarding participation, a "California Earthquake Risk Colloquium" to weigh the potential benefits and costs of enhancing seismic performance in buildings and provide direction to the developers of future design and construction guidelines. The CBSC should use the results of the "Colloquium" and take steps to implement its recommendations with assistance in testing and applied research from the Center for Earthquake Risk Reduction. The Commission suggests that, as a reasonable goal, the state should support the development of comprehensive building design guidelines so that they are available by the year 2000.

Recommendation

The Commission recommends that:

- The Governor support and participate in a special high-level task force, the "California Earthquake Risk Colloquium," a meeting convened by the Commission to recommend acceptable levels of earthquake risk and performance objectives consistent with those levels.

Testing and Research

The state should immediately begin to correct the practice of relying on unverified technical changes to the building code. However, it will take sustained efforts over many years to solve all the existing problems, let alone those related to future technical developments.

The Commission, in response to a legislative mandate, recently proposed a new Center for Earthquake Risk Reduction. The center would have as its primary responsibility the goal of securing state, federal, and private-sector funding for solving high-priority earthquake problems. In consultation with the CBSC, it should focus first on verifying unsubstantiated code changes as one of the state's most pressing seismic safety needs.

A second, and equally important, objective would be to improve the transfer and use of new technology. A concerted, long-term effort is needed to improve the use of available knowledge in the codes and in the design and construction professions.

Another key goal would be to achieve desired performance for new and existing buildings. This goal includes developing a better understanding of the behavior of building systems, correlating system performance in earthquakes with codes and practices under which they were con-

structed, and improving quality control, design, construction, and retrofit measures. The new center would address the shortcomings in the current building code.

The authority to create this center exists in the Government Code, but state funds are needed to fulfill the mandate and to influence, focus, and expedite the applied technology efforts within local, state, and federal governments and the building industry. A modest initial state investment of $5 million—one-tenth of 1 percent of the losses in a moderately damaging earthquake—could establish the Center for Earthquake Risk Reduction and fund its initial efforts (SSC, 1994e).

Recommendation

The Commission recommends that:

- Legislation be enacted to authorize funds for a Center for Earthquake Risk Reduction with a sustained funding source to help achieve desired earthquake performance for new and existing buildings.

Need for Response Data

Response data are vital to understanding the behavior of buildings during earthquakes. Unfortunately, many damaged buildings in southern California were not adequately instrumented. For example, only one confirmed set of records was obtained from hundreds of damaged steel buildings.

Prior to 1971, the City of Los Angeles adopted an ordinance requiring building owners to install three strong motion recorders in buildings over nine stories. When the San Fernando earthquake occurred, these instruments yielded an invaluable set of data on ground motion and building response that for many years served as the basis for revisions to building analysis and design. This program became a worldwide model of a successful municipal strong-motion instrumentation program. In 1983, however, the Los Angeles program was modified to require only one instrument per building, located at the rooftop. Following the Northridge earthquake, 490 records were recovered from 300 buildings. Approximately 100 of these records were from older buildings with two or three instruments; the remaining records were from buildings with only one instrument. Data from only one instrument give some indication of the performance of a building but do not permit detailed study of building's response. A much more aggressive program of instrumentation of buildings in California is needed.

"How safe do we have to be, and how much are we willing to pay for it?"

Recommendations

The Commission recommends that:

- The California Strong Motion Instrumentation Program (SMIP) develop a program to encourage all municipalities in Seismic Zone 4 to designate significant buildings in their jurisdictions and to adopt building instrumentation ordinances that require owners of these buildings to install and maintain at least three strong-motion instruments in each.
- SMIP develop and adopt standards for the installation and maintenance of building strong-motion instrumentation and provide for processing, archiving, and disseminating records obtained from buildings instrumented according to these standards.

Reducing Nonstructural Hazards

Structural elements—beams, girders, flooring, roofs—hold buildings up. Nonstructural elements are attached to provide specific functions. Some nonstructural elements—ornamentation and appendages (such as cornices and statuary), chimneys, tanks, signs, storage racks, suspended ceilings, raised access floors, permanent floor-supported cabinets, book stacks more than five feet tall, and electrical or mechanical equipment requiring anchorage—are covered by the building code, but furnishings and most equipment are not (see Figure 27). Building contents are installed by owners without government oversight to ensure their seismic safety.

The Northridge earthquake caused nonstructural property losses estimated in the billions of dollars.

There are three kinds of risk from nonstructural hazards:

- Risk of injury
- Risk of property loss
- Risk of interruption of function

The Northridge earthquake caused nonstructural property losses estimated in the billions of dollars. Safety was compromised when heavy light fixtures fell and massive pieces of building veneers and ceilings were dislodged, though the early hour that the earthquake occurred reduced fatalities. One insurance company with a $60 million commercial earthquake policy loss found that the majority of the claim was due to only one kind of damage—nonstructural sprinkler pipe failures. The majority of the approximately $300 million in damage to Los Angeles Unified School District facilities was also nonstructural.

Interruption of essential functions, such as the failure of backup power generators at fire department dispatch centers (for example, Los Angeles City Fire Department) and hospitals (for example, Los Angeles County's Olive View Medical Center) have life safety consequences. Interruption of business functions, such as corporate data processing centers and unoccupiable industrial, commercial, and residential buildings, can have economic consequences that may exceed the cost to repair and replace damaged elements. In many buildings, damage to the mechanical systems, including heating, ventilating, and air conditioning (HVAC) equipment as shown in Figure 28, resulted in lengthy downtime.

Other nonstructural damage in the Northridge earthquake included:

- *Water leakage* from broken sprinklers and other piping was particularly prominent. Opinions vary as to whether the use of the 1991 edition of NFPA-13, the standard that guides the installation of fire-sprinkler piping including seismic bracing requirements, would have prevented most of this damage. Very few buildings had sprinkler piping installed according to this recent standard, so the earthquake largely tested older standards. Related to sprinkler performance is the behavior of nearby nonstructural components such as suspended ceilings, light fixtures, and ductwork. Most sprinkler failures were caused by flexible suspended ceilings swinging and hitting rigid fire-sprinkler lines. The design professions (especially the architect and the mechanical engineer or specialists such as fire-protection engineers within the mechanical engineering discipline) and subcontractors do not coordinate their work closely enough, so the building ends up with a mixture of nonstructural components that sometimes defeats the earthquake-resisting details of the individual systems. The impact of water leakage that prevented the functioning of hospitals in the region of strong shaking was particularly devastating.
- *Water heaters* toppled in the earthquake, causing damage from water leaks, gas leaks, and fires. Though state laws and the building code require the bracing of newly installed water heaters, many existing water heaters were installed before these laws existed, or they were installed without permits or in violation of the building code. Existing laws also require manufacturers of water heaters to include bracing instructions and warning labels for new heaters, but these laws have not been enforced. Water heaters have also posed risks of injury to occupants who are struck as they topple or when they obstruct exit ways.
- *Elevators* have been subject to retrofit requirements in California for over a decade; October 1982 was the deadline for compliance with Title 8 Elevator Safety Orders of the California Administrative Code. New elevators have been installed with additional earthquake protection features, chiefly a self-shutdown sensor and improved bracing of the heavy counterweights that are used in cable-traction systems. The 1971 San Fernando earthquake was the chief motivation for this upgrading of elevator earthquake regula-

tions. One of the most serious kinds of elevator damage, which can cause injuries as well as lack of service, is derailed counterweights: 674 derailed in the 1971 event, and the number that came out of their guide rails in the Northridge earthquake was almost the same—688. Although the earthquake occurred at 4:31 a.m. when few elevators were in use, a CalOSHA survey of elevator companies found that occupants had to be rescued from 39 elevators.

- *Hazardous material spills* caused by nonstructural damage, such as toppling of contents in laboratories, were documented in detail at the CSU Northridge campus, where chemical spills occurred at over 200 locations. Releases in three of the four science buildings resulted in fires, all in labs where organic solvents were in use. Approximately 50 compressed-gas cylinders were badly damaged in these fires, and another 50 exploded. Few or none of the most likely sources of hazardous material releases in a typical laboratory are covered by the building code, since storage of contents is outside the code's scope. Thus, regardless of improvements in the UBC's nonstructural provisions over the years, hazardous material spills are likely to continue to happen in earthquakes unless other controls and programs dealing with occupants' use of buildings are implemented.
- *Exterior plaster soffits* (exterior ceilings and overhangs) and wall finishes failed in several buildings that are considered modern (see Figure 26 and Figure 67). Under present inspection practices it is difficult to verify that these elements were constructed with adequate anchorage because several installation steps are involved, and detailed inspections of each phase are not a typical building inspection practice. Once in place, verification is even more difficult. Whereas the earthquake bracing of a lightweight suspended ceiling can usually be inspected by removing the acoustic ceiling tiles, the equivalent procedure for stucco or plaster may require destruction of some of the material.
- *Storage racks*, used in retail warehouse-type stores, performed well in some facilities but poorly in others. Heavy contents fell off racks as well (see Figure 29). The difference between acceptable and unacceptable performance appeared to be related to owners' differing policies. Owners of the better-performing racks purchased racks with heavy storage load ratings, loaded them to only about half their capacity, and kept upper-level items shrink-wrapped together in relatively large and stable blocks. Others purchased less sturdy racks, filled their space with heavy contents, and allowed individual items such as 5-gallon paint cans to be stacked on upper levels.
- *Freestanding masonry walls* (concrete-block fences) suffered widespread failures. Four- to six-foot-tall concrete-block fences fell because they were not well engineered; many were obviously built without any inspection. Some had no foundations, some lacked reinforcing, and where reinforcing was used, it was often ineffective. Similar failures occurred in the 1971 San Fernando earthquake. These deficiencies are all solvable when such walls go

Reitherman

Figure 26. Heavy plaster ceilings or soffits can pose serious risks to occupants.

Winslow

Figure 27. Unsecured tall, heavy furniture can strike or trap occupants. Building owners, managers, and occupants are primarily responsible for securing them.

Lizundia

Figure 28. Broken supports on heating and ventilating equipment can render this equipment useless.

through a building-permit process and either a design professional or standard details are used. Table 23-P of the 1991 UBC prescribes a force factor for masonry or concrete fences over six feet high, but typical zoning regulations keep almost all such walls from exceeding that height and not all local building departments require permits for such walls.

- *Suspended ceiling* performance in the Northridge earthquake was similar to that in other recent California earthquakes. Unbraced or less-than-completely-braced ceilings frequently dropped tiles, and sometimes entire T-bar gridworks were damaged and partially fell. In a department store in Sherman Oaks, part of one floor had been remodeled and the ceiling had been brought up to recent code requirements, which included diagonal tension wires and vertical compression struts and light fixtures with their own vertical support wires. Damage to the older part of the ceiling was extensive, but not one ceiling tile or light fixture from the remodeled section fell during the earthquake, indicating the effectiveness of these features.

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Figure 29. Collapsed storage racks would have posed substantial risks to life had this building been occupied during the earthquake.

- *Storefront window breakage* was common throughout the San Fernando Valley, but it was unusual to find more than a few percent of the windows in large multistory buildings broken. One possible explanation is that typical midrise or highrise buildings benefit from better architectural-engineering attention to the effects of building drift on window assemblies than the typical one- or two-story commercial building receives.

  Breakage of glass often occurs at entries to buildings, a location that maximizes the potential for injuries. Aftershocks are a particular danger with this nonstructural component. The broken panes pictured in Figure 30 were misaligned and some cracked in the main shock at 4:31 a.m., but it was an aftershock that caused the panes to fall out. Figure 31 shows how such buildings are posted with placards, raising the issue of whether nonstructural post-earthquake safety criteria need more emphasis.

The Commission believes that had the earthquake occurred during a normal work or school day, there would have been many deaths and injuries from nonstructural failures. Losses from nonstructural damage were significant, and measures are needed to reduce damage in future earthquakes.

Nonstructural elements should not pose a risk to life. Tenants and owners should be able to better anticipate the amount of damage and length of interruption from such damage. Performance of nonstructural elements has improved over the past several decades, but three major problems remain to be solved:

- Nonstructural components are more vulnerable to damage at low-to-moderate levels of shaking than structural elements. Even at higher levels of shaking, nonstructural property losses may still exceed structural damage because they are so widespread.
- Nonstructural elements receive less detailed architectural and engineering attention and less building-inspection effort to ensure conformance with code requirements than do structural elements.
- The complete “collapse” of a nonstructural element is not always a major threat to life, property, or building function. The specific performance objective, or acceptability criterion, for a nonstructural element in a particular kind of building must be considered (Figure 32).

The Commission believes that nonstructural damage can be mitigated by a series of discrete changes to codes, standards, retrofit policies, and installation practices. For example, the City of Palo Alto requires ceilings, lights, and ducts to be braced during renovations, even if they are not directly a part of renovation (Palo Alto, 1991). In addition, recommendations made in this chapter on quality of design and construction should provide significant improvements in mitigating nonstructural as well as structural vulnerability. The Commission believes that standards for new construction and retrofits need to be developed and made mandatory for such nonstructural building components as fire sprinklers and water piping leak control valves, storefront window assemblies, and emergency power systems.

Recommendations

The Commission recommends that:

- The Division of the State Architect draft nonstructural standards for new construction and retrofits and submit them to the CBSC to be made mandatory by reference in the California Building Code.
- CBSC amend the California Building Code to require a quality assurance plan for all engineered buildings for the design and installation of nonstructural bracing.
- CBSC amend the California Building Code to require the design professional of record to delegate design, coordination, and field review responsibilities for nonstructural building components.
- The Public Utilities Commission work with utilities to develop a program to allow gas utilities to include checks for water heater braces in their routine service calls, to notify building owners if water heaters are not properly braced or equipped with flexible gas lines, and to encourage or require retrofits of water heaters within a reasonable period of time.

Making Existing Buildings Safer

The Commission believes that the greatest seismic risk in California today comes from vulner-

Reitherman

Figure 30. Large broken windows at a hotel entrance pose major falling hazards.

able existing buildings. Though only a small proportion of these are likely to have life-threatening failures or collapse in an earthquake, the risk they pose is great. Most of the recommendations in this report call for actions that will reduce the vulnerability of structures not yet built, but changes in tomorrow's building codes and enforcement practices will not reduce the risks associated with existing vulnerable structures.

Reitherman

Figure 31. Typical "green tag" placard used to post buildings as safe to occupy. It states nothing about hazards from nonstructural elements or building contents.

Only a small percentage of existing buildings are demolished or renovated in any year. The numbers may vary from locale to locale and for different types and uses of buildings, but it is likely that, unless a major urban earthquake occurs, at least 90 percent of the buildings existing in

Reitherman

Figure 32. A light fixture partially fell when an anchor for one of its two safety wires pulled out at the Sylmar County (Olive View) Hospital.

Owners have the most to lose in earthquakes and the most to gain from retrofitting.

California today will still be in use ten years from now—and posing the same threat that they pose today.

With each new earthquake, including Northridge, we gain greater understanding of which building types, structural systems, details, and nonstructural elements are particularly hazardous. We know the types of "older" buildings that pose potentially significant life safety risks. The 1976 UBC is often used as the benchmark for identifying older engineered buildings. Many engineered structures built to pre-1976 codes are fine, but some pose unacceptable risks. The 1976 date, generally applicable to engineered

Alcorn, Los Angeles Times

Figure 33. Both ends of this 1960s medical office building collapsed and the second floor "pancaked." Fortunately it was not occupied.

structures, is not a valid date for conventional light-frame construction, which includes most homes. Conventional construction is considered "older" if built to codes older than 1949-1960, depending on the jurisdiction.

A number of building types are vulnerable to earthquakes, and in the Northridge earthquake they again demonstrated their potential to collapse and pose significant threats to life and loss of building functions. For example, the concrete columns and beams in buildings erected before the mid-1970s often lack reinforcing steel to keep them from collapsing or being damaged beyond repair in earthquakes. These buildings, like the ones shown in Figure 33, can pose the greatest threat to life in earthquakes because, though there are just a few of these buildings throughout California, they often house large numbers of offices. Just one collapse could cause hundreds of deaths. In the 1971 earthquake, three such hospital buildings in the San Fernando Valley collapsed, killing 52 people. Figures 34 through 37 show other building collapses in the Northridge earthquake.

Building types with a high risk of collapse include nonductile concrete frames, URMs, tilt-up concrete walls, precast and prestressed concrete elements, and inadequately braced, or "soft," first stories. Above-grade concrete parking structures and concrete or steel-frame buildings with URM infill are also commonly regarded as potentially hazardous in earthquakes. Engineers or architects evaluating such buildings may find them unsafe for occupancy.

Unfortunately, little information is available concerning the total number of buildings of various types and their locations to help in planning and carrying out retrofit programs. The experience after the Northridge earthquake shows that there is no systematic collection of information on good or poor performance of the various building systems. Much of the information collected has been anecdotal and thus is likely to be incomplete and biased. Each community should consider developing a database containing information on structural type, age, size, location, and occupancy of each vulnerable building in the community to estimate the number of buildings expected to be damaged in an earthquake and to encourage owners to decide whether their buildings should be retrofitted. In addition, the database would allow for much more realistic use of hazard mapping results and emergency planning scenarios.

Efforts to upgrade or retrofit existing structures pose complex policy and engineering issues including identifying and evaluating specific vulnerable structures, setting priorities for retrofit, establishing uniform retrofit standards and performance objectives or acceptable damage levels, providing appropriate incentives to encourage mitigation, and in some cases mandating action.

It is important to stress that though state and local government will suffer indirect losses caused when private structures are damaged, it is the building owner—public or private—who bears the brunt of the loss and liability for injuries. Owners have the most to lose in earthquakes and the most to gain from retrofitting.

Building owners, whether individuals or companies in the private sector, school and hospital boards, or state or local agencies are responsible for the performance of their buildings. Legal defenses based on not knowing of a structure's vulnerability will fall on deaf ears. A 1985 legal opinion by the Attorney General states that an engineer who determines that there is an imminent risk of serious injury to the occupants of a building and who is advised by the owner that no disclosure or remedial action is intended has a duty to warn the identifiable occupants or, if that is not feasible, to notify the building official or other appropriate authority of such determinations. The state and local governments can help reduce the uncertainties involved in retrofitting or demolition by encouraging planning and providing decision-making methodologies, standards, and incentives.

As difficult as identifying hazardous building types may be, it is relatively easy compared to the more controversial task of deciding which buildings are so vulnerable that retrofit or demolition should be mandated. There are limited data from earthquakes on building performance. In most earthquakes, only the damaged buildings are surveyed, and the lessons on good performance typically go unnoticed. In addition, the use or occupancy category of a building, its age, and its location all play a role in how vulnerable the building may be.

Retrofit Standards

Standards for retrofitting vulnerable structures are not addressed in the building codes, and there is no broad consensus on performance objectives for retrofits or on standards to meet them. However, FEMA is making a major push to develop standards for retrofitting buildings, including varying performance objectives, by funding a five-year, $8 million effort that is being directed by BSSC through the National Institute of Building Sciences. The primary subcontractor for the development of the provisions is ATC, a California-based nonprofit buildings research organization, and the majority of the engineers and researchers working on this project are from California.

Tobin

Figure 34. If buildings such as this had been occupied, hundreds would likely have been killed during the Northridge earthquake. This building was incompletely retrofitted after the 1971 earthquake, which may have hastened its demise in this event.

California already has some experience with these issues. There are both statewide and local programs aimed at reducing the risk from existing structures. The Unreinforced Masonry Law of 1986 provided a backdrop against which many different types of programs can be examined. Apart from mandatory inventory and notification requirements, the URM Law left determination of whether risk mitigation should be required to the local jurisdiction (see Figure 38). Although this provided significant flexibility, it also resulted in a high level of conflict between building owners and local governments. In addition, it created a variety of unequal strengthening programs across the state, resulting in significantly different levels of risk to life and property. Most communities with retrofit programs use some method of establishing retrofit priorities that involves at least occupant exposure and building type and occasionally geological considerations.

The general plan is the local government's policy document for balancing the community's opportunities and problems. Reducing seismic risk from vulnerable existing buildings should be a consideration in these decisions. Each city and

county and state agency must decide how to carry out retrofit policies that take into account the availability of funds; local economic, social, and geologic conditions; community values; and seismic risk. The general plan can be an appropriate tool for developing and conveying these policies. For more information and recommendations on land use planning, see Chapter V.

Providing incentives is critical to encourage the retrofit of privately owned buildings. Palo Alto adopted an ordinance that had limited success in encouraging voluntary retrofits; it requires seismic risk evaluation but offers waivers of certain zoning requirements to those who strengthen buildings.

Schmid

Figure 35. Although this retrofitted building lost a few bricks and may be difficult to repair, damage was significantly less than in similar unretrofitted buildings. The outer layer of brick was not adequately connected to the inner layers.

Recommendations

The Commission recommends that:

- Legislation be enacted to require that, by the year 2000, local general plan safety elements contain a generalized description of all typical building types and vintages in the community's neighborhoods, with a special emphasis on those vulnerable to collapse from seismic hazards, and a plan to mitigate the risk from these structures.
- Legislation be enacted to require state and local building code enforcement agencies to identify potentially hazardous buildings and to adopt mandatory mitigation programs by the year 2000 that will significantly reduce unacceptable hazards in buildings by the target year of 2020.
- The Seismic Safety Commission, in conjunction with the California Office of Planning and Research and other interested organizations and agencies, develop guidelines for state and local governments to use to identify potentially hazardous buildings, amend safety elements, and prepare mitigation plans.

Similar efforts and guidelines were undertaken in 1986 for the retrofit of URM buildings in California. These recommendations call for a similar approach for other types of buildings that are known to be hazardous to life.

Retrofitted Buildings

The Northridge earthquake was one of the first earthquakes in which a large number of structures that had been retrofitted for seismic resistance experienced strong shaking. Though the results are difficult to assess with precision, retrofitted buildings typically withstood strong motion better than their unstrengthened contemporaries.

Unreinforced Masonry Buildings

Los Angeles pioneered the retrofit of URM buildings under a program known as Division 88, the city ordinance where it appears. The key objective of Division 88 is to "reduce the risk of life loss." It is not intended to ensure that lives will not be lost, only that the risk will be reduced. Moreover, the performance objectives do not preclude damage so significant that a building might not be economically repairable.

Of the approximately 5,900 retrofitted buildings (most of which were not in the San Fernando Valley region, which was the most heavily shaken), about 400 were damaged in the Northridge earthquake, about 50 so heavily that they had to be demolished. In the City of Los Angeles, 213 retrofitted URM buildings suffered moderate damage and six commercial URM buildings had partial roof collapses (Figure 34). In Glendale, there were 267 retrofitted URM buildings, of which 17 were red-tagged. Burbank had 16 retrofitted URM buildings, of which only one was red-tagged. There was not one loss of life in any of the 1,400 strengthened residential URM buildings (containing 37,000 units) in the City of Los Angeles—most of which were fully occupied at the time of the earthquake—although a significant number of them were in areas of intense, albeit short-duration, shaking.

Damage and partial collapses in unstrengthened URM buildings—particularly in Fillmore and parts of Santa Monica—were noticeably more severe than in similar retrofitted buildings nearby and in other communities. Of the 64 unstrengthened URM buildings in Fillmore, most were severely damaged; many have since been demolished. Clearly the Northridge earthquake reconfirmed that strengthened URM buildings perform better than unstrengthened URM buildings (Figure 36).

Whether the performance of retrofitted buildings for this size earthquake was acceptable remains an open question, but many engineers view the performance of retrofitted buildings in the Northridge earthquake positively. One engineer who helped to develop Division 88 went so far as to call it “an unqualified success” after review of damage following the earthquake (Schmid, 1994b). Another engineer states that “overall, the City of Los Angeles retrofit program (Division 88) must be judged a success in the Northridge earthquake” (Hamburger and McCormick, 1994b). Many others appear to agree and note that no lives were lost and damage to the total stock of retrofitted buildings was significantly lower than damage to similar unretrofitted buildings, such as in Fillmore.

However, some engineers have pointed out that while the percentage of significantly damaged retrofitted URM buildings is small across the entire sample, this is partly because there were few URM buildings in the San Fernando Valley area and north where shaking was greatest. In the isolated pockets where there were retrofitted URM buildings and where shaking was intense, such as West Hollywood and Santa Monica, damage to retrofitted URMs was greater than damage to other buildings. The early-morning occurrence of the earthquake is also believed to be a significant factor; had the event occurred at noon on a work day, when pedestrians were on the street and at risk from collapsed parapets and upper-story wall failures, results and reactions would have been different.

A number of engineers and building officials attribute much of the significant damage to poor design and construction, not to the code itself. Some investigators reported that the damage in retrofitted URMs appeared to be in large part caused by design or plan check errors and lack of adequate quality control, citing numerous instances where unbonded brick veneer was incorrectly used in calculations of wall height-to-thickness ratios. There were also reports of buildings that appeared to have low mortar strength but were assigned much higher values by the original testing laboratory and reports of drawings that did not conform to the buildings being strengthened. In addition to stating that quality control was a more severe problem than the Division 88 standards, a city task force also recommended a number of specific code changes. The fact of the matter remains that URM buildings are brittle, vulnerable structures, and the degree to which seismic improvements can be made is limited by economic feasibility.

Many owners were unaware that a retrofitted building could still be damaged to the point of not being economically repairable. For example, the South Central Southern Missionary Baptist Church spent $250,000 on earthquake reinforcement three years before the earthquake but, following the earthquake, the Reverend J. L. Gates stated, “There is no question we’ll have to tear it down” (L.A. Times, 1994). Lula Washington, director of the Los Angeles Contemporary Dance Theatre, whose West Adams Boulevard headquarters was significantly damaged, observed, “When

Figure 36. The entire facade of this unretrofitted brick building in Fillmore was lost. The city contemplated requiring retrofit measures but concluded as recently as 1993 that they were economically prohibitive.

The Northridge earthquake reconfirmed that strengthened URM buildings perform better than unstrengthened URM buildings.

Figure 37. This retrofitted brick building collapsed in part because its wall braces were ineffective.

I saw this building, I almost collapsed myself. We reinforced for over $200,000 in 1992" (L.A. Times, 1994). The distinction between life safety risk reduction and damage control is not well understood by many owners of retrofitted buildings (Figure 37).

In summary, retrofits of URM buildings significantly reduce, though they do not eliminate, the risk to life. However, many owners have obviously not been informed about the limitations of retrofitting. From an investment standpoint, since retrofitted URM buildings clearly may not be functional or economically repairable after moderate earthquakes, owners or potential owners considering retrofits must take the anticipated costs of repair into account, in addition to the immediate costs of the retrofits, when deciding whether to retrofit or replace.

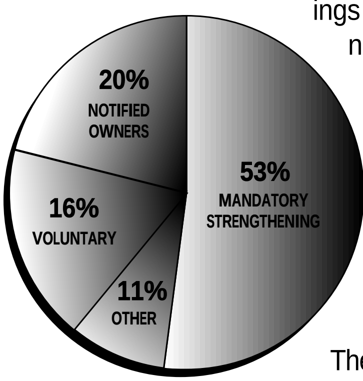


Figure 38. Types of programs instituted by local governments in response to the state's URM Law.

Effects of the URM Law

The URM Law was passed in 1986, requiring that local jurisdictions survey their communities for URM buildings and establish risk-reduction programs that, at a minimum, included notification to the owners that their buildings were potentially hazardous. By 1992:

- 20 percent of the communities had "complied" with the law with ineffective URM programs that only notified the owners and did not require them to take any action (Figure 38).
- About 16 percent had chosen voluntary strengthening programs that were only somewhat more effective in actually reducing earthquake risk. Most URM buildings in these programs remain unstrengthened today.
- About 53 percent of the communities require mandatory retroactive strengthening of URM buildings. This effort has resulted in the strengthening of about 50 percent of the targeted 25,000 buildings and over $2 billion in retrofit expenditures by private and government owners. An additional 15 percent of the buildings (approximately 3,800) are likely to be strengthened in ongoing mandatory strengthening programs between now and the end of the century (Figure 39).
- 11 percent had some other type of program.

In the Northridge earthquake, the mandatory retroactive strengthening efforts of several cities, led by Los Angeles, made a substantial difference. They dramatically reduced damage and life-threatening situations in URM buildings. Voluntary strengthening programs and other URM "risk-mitigation programs" that simply involve the notification of owners that they own potentially hazardous buildings are clearly not effective for risk mitigation. Moreover, such programs essentially violate the Legislature's intent of state-mandated local programs by delaying proactive risk-reduction measures and prolonging undue public exposure to life-threatening buildings.

Fillmore notified its URM owners but never adopted an official URM risk-mitigation program. All owners were notified of the risk posed by their buildings long before the earthquake, and the city council debated the merits and costs of retrofitting. However, because the rents are too low in Fillmore to generate sufficient funds for major capital outlays in many of these buildings, Fillmore in 1993 reluctantly chose to forego efforts to reduce seismic risk in their buildings. Mr. Roy Harthorn, Santa Barbara's building official, who assisted the city staff in evaluating

Fillmore's seismic risk, described the situation as follows:

> The city council faced a dilemma of choosing either an overly burdensome mandatory program with effective measures that economically would not materialize, or to enact a voluntary program that would lack sufficient impetus to be effective. I interjected that there was considerable middle ground to consider such as longer term deadlines in the 10 to 20 year range, property resale trigger mechanisms, re-roof trigger mechanisms and other less burdensome trigger mechanisms designed to minimize fiscal impacts on the property owners (Harthorn, 1992).

This same scenario has occurred in numerous other cities such as Whittier, Pomona, Oakland, Santa Cruz, Watsonville, Hollister, and Coalinga.

Existing state laws also encourage limited disclosure of general seismic safety information at the time of sale of all commercial buildings. State law also requires owners to place placards warning the public about earthquake risk at the main entrances to URM buildings. However, no government agency is responsible for enforcing these laws, so compliance is spotty at best. Even if governments required a formal disclosure of seismic risk that included a clarification of the benefits and limitations of retrofitting, most building owners are still not equipped to understand or manage their seismic risk in any comprehensive way.

Seismic risk has greatly reduced the market value of unstrengthened URM buildings, but rental rates are still controlled by local market rates. Therefore, private owners of URM buildings typically have difficulty securing loans for seismic retrofits and are unable to raise rents to establish a source of revenue to pay off retrofit costs without losing tenants. Some local government owners have established bond programs to finance retrofits of their own buildings, but very few local governments have created financial, land use, and zoning incentives for seismic retrofits of private buildings, although state laws have recently been changed to make it easier to create programs such as assessment districts.

Recommendation

The Commission recommends that:

- The Legislature revisit the state's 1986 URM Law and consider appropriate actions to address the inequities and the public's continuing exposure to risk that have resulted from the failure of a significant number of local governments to comply with the intent of the law so that approximately half of the state's URM buildings remain unstrengthened.

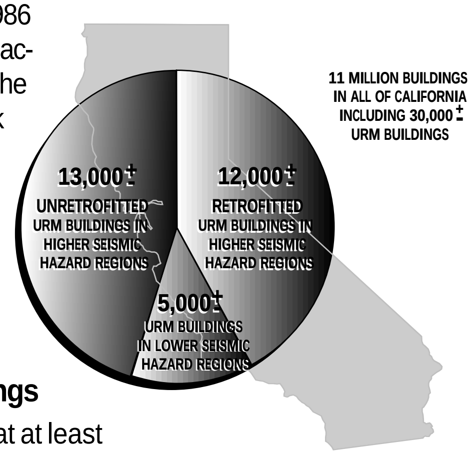


Figure 39. Approximate numbers of URM buildings, retrofitted and unretrofitted, in California.

Other Types of Retrofitted Buildings

Preliminary information indicates that at least five retrofitted nonductile concrete-frame buildings performed adequately: three in Los Angeles, one in Santa Clarita, and one in Topanga Canyon.

- The three buildings in Los Angeles, all located on the UCLA campus, are seven-story student residence halls originally constructed in the early 1960s. A structural evaluation in 1981 indicated several hazards in the structures, including a potential column shear failure, a lack of confinement in the columns, a potential strong-beam, weak-column mechanism, and potential column damage under the discontinuous walls. The retrofit involved concrete jacketing the concrete moment-frame columns and lower-level spandrels and adding new concrete walls below the discontinuous walls or strengthening the columns below those walls. All three buildings performed well with only minor damage, but the shaking from the Northridge earthquake was estimated to be a relatively weak 0.15-0.20g at that site.
- The Santa Clarita building is a two-story commercial building with post-tensioned concrete flat-slab floor and roof and 30-inch-square concrete columns that originally relied on flat-slab moment-frame

EQE

Figure 40. This building in Santa Clarita is shown during its 1993 retrofit which was undertaken with minimal disruption to its occupants. The building emerged from the Northridge earthquake with no structural damage.

Most building owners are still not equipped to understand or manage their seismic risk in any comprehensive way.

behavior for lateral resistance. The building was strengthened in 1991 by adding new concrete beams above the floors in selected locations to form frames. These beams were designed to cause yielding in the new beams rather than the existing columns. The retrofit design was based on the 1988 UBC. This building experienced intense shaking with remarkably little damage (Figure 40).

- The Broadway Store at Topanga Plaza, a retrofitted concrete-wall building located a little over four miles from the epicenter, is a three-story building with waffle-slab floors and was originally constructed around 1964. A 1989 structural evaluation indicated a potential weak story at the ground level, and two shotcrete walls were added at the ground floor. The building suffered significant cracking to both the original concrete and the added shotcrete walls at the first floor as well as significant damage to the adjacent concrete columns. The mechanical penthouse and roof screens were also significantly damaged. Lack of preparation of construction joints in the original walls appears to have contributed to this damage.

A retrofitted concrete-wall industrial building located three miles from the earthquake epicenter fared better. This eight-story building was constructed in 1953 and conservatively retrofitted in 1989 by thickening some existing walls and adding new walls. Nearby ground motion records indicated relatively moderate levels of ground shaking. Following the earthquake, the only observed damage was some minor to moderate cracking in the walls, about the amount expected by the designer and owner for this level of shaking. The building was tagged green.

Only one example of a retrofitted wood-frame apartment complex is known to exist in the region of intense shaking. The building is a three-story, 200-unit complex with tuck-under parking located in Sylmar, approximately seven miles from the epicenter. It was originally built about 1963 with gypsum wallboard and gypsum lath-and-plaster wall cladding providing the lateral force resistance in the upper levels in the longitudinal direction and at the ground level. Several diagonally sheathed walls provided lateral resistance at the ground level but only in the transverse direction. All ground level walls were extensively damaged in the 1971 earthquake. The building was strengthened with plywood walls at the ground level following the 1971 earthquake. Observations following the Northridge earthquake indicate that it performed well, with little structural damage (figures 41 and 42).

The Northridge earthquake reconfirmed observations from past earthquakes regarding buildings with incomplete retrofits. If force paths through such buildings are left incomplete or improperly detailed, the potential for collapse can actually be greater than for unstrengthened buildings. For example, the Bullock's building in the Northridge shopping mall was partially retrofitted shortly after the 1971 San Fernando earthquake, but the added walls were not actually connected to columns as required by the retrofit plans, making the walls discontinuous, which probably exacerbated the collapse of three levels of concrete. The lesson here is that extra care must be taken in retrofitting to ensure complete load paths, attention to details, and integrity of vertical load carrying systems.

Although there were retrofitted structures that suffered significant damage and even collapse, the performance of retrofitted structures including significantly reduced damage, deaths, and injuries in the Northridge earthquake was, on the

whole, successful. In those instances where the performance was lacking, quality concerns in either design or construction were noted. A lack of quality is not acceptable for any construction activity, retrofit or otherwise.

Recommendations

The Commission recommends that:

- Legislation be enacted to require owners of potentially hazardous buildings to disclose seismic risk to potential buyers at the time of sale, to lenders, and to tenants on entering into or renewing leases, or when they relocate within a building.

  The disclosure should include pertinent information about the risks of damage, ways to reduce risk and the benefits, costs, and limitations of seismic retrofits.

- Legislation be enacted to allow the warning placards required by existing law to be removed from potentially hazardous buildings that have been retrofitted in substantial compliance with the Uniform Code for Building Conservation, Appendix Chapter 1, provided that the disclosures in the preceding recommendation take place.
- Legislation be enacted to require owners and business operators to include warning placards at the entrances to hazardous buildings of all types as well as seismic risk management and response plans as part of their overall emergency plans for safety in the workplace.
- The Governor direct CalOSHA to inspect, cite, and fine employers and operators when these earthquake warning placards and plans are not present during inspections of workplaces.

Issues for Specific Building Types

Quality control, building codes, nonstructural hazards, and the other issues addressed so far in this chapter apply to virtually all types of buildings. Discussed below are some issues that relate primarily to one or only a few types of buildings or building uses.

Mendes

Figure 41. Damage from the 1971 earthquake in this apartment was similar to damage in the 17 ghost towns created by the Northridge earthquake.

Single-Family Dwellings

In general, single-family dwellings are the safest type of building to be in during earthquakes, but old or poorly built or maintained homes are vulnerable to damage. These present a substantial economic risk to Californians.

Mendes

Figure 42. Walls in this building were repaired and retrofitted with plywood after 1971. In 1994 it suffered only minor damage.

Tens of thousands of one-story single-family wood-frame houses were damaged in the Northridge earthquake. However, a study performed for the Department of Housing and Urban Development that analyzed a random sample of several hundred wood-frame structures within a ten-mile radius of the epicenter found that single-family detached properties had remarkably low levels of serious damage: 90 percent of the structures had no foundation damage, 98 percent had no wall-framing damage, and 99 percent had no roof-framing damage. Nevertheless, over 19,000 single-family homes suffered damage in excess of $10,000 (Comerio, 1995) in the County of Los Angeles alone, and of those about 1,900 still remained vacant in September of 1994. In addition, 10,000 single-family homes had losses from $5,000 to $10,000 (LAHD, 1994).

Russell

Figure 43. This home was retrofitted just prior to the earthquake and sustained far less damage than similar, unretrofitted homes in the neighborhood.

If left incomplete or improperly detailed, a "strengthened" building can be more likely to collapse than an unstrengthened one.

Typical structural damage in single-family homes was not spectacular or life-threatening. It consisted of cracked stucco, walls cracked at garage door openings and at narrow first floor sections of walls, fallen roof tiles, and stucco cracking at the foundation line. Interior damage to gypsum board, finishes, and contents was also common; many chimneys fell; and a few hillside homes collapsed or partially collapsed. Some foundation cracking and settlement was noted, especially in older homes. Even though most of this damage sounds minor, repair costs exceeding $100,000 are not uncommon.

Homes will always suffer some damage from shaking as intense as the Northridge earthquake. Cracking and minor damage cannot be reasonably avoided, but major damage, life-threatening failures, and loss of habitability can (figures 43 and 44). Homes are vulnerable because their design balances seismic resistance with the attractiveness of the home and the cost of construction. The safest building style—a simple one-story wood box on a level lot with only a few small windows and doors—would not be very attractive. The features that make homes more attractive and functional—steeply sloping lots, second stories, split levels, high ceilings, sliding glass doors, and large windows—also increase vulnerability to earthquake damage. Most homeowners would no doubt be willing to risk some earthquake damage, including significant amounts of minor damage, to balance architectural amenities with earthquake safety as long as homes remain habitable.

Building codes are intended to save lives but not to prevent all damage. With the exception of the failures of homes on steep lots in which three persons lost their lives, the safety and health aspect of this intent language was essentially met in the Northridge earthquake. Determining a level of non-life-threatening damage that would be acceptable for a single-family residence is difficult. Views will differ before and after damaging earthquakes and are highly dependent on the perspective of the person asking the question.

A clear public policy statement on acceptable levels of risk in dwellings has never been made in California by the Legislature or any administrative agency. In Chapter VI, the Commission recommends that the Governor support an ad hoc "California Earthquake Risk Colloquium" convened by the Commission to develop a policy on acceptable levels of risk. The Commission believes that an appropriate goal for acceptable performance for new residences should be that:

- Substantial life safety is provided by building elements regulated by the building code (which excludes furniture and contents).
- At worst, the extent of damage is such that residences can be occupied after inspection.

The 1994 UBC changes for conventional light-frame construction, which include a tightened definition of that term, will go into effect in California jurisdictions in July 1995. These amendments are essentially sound and, with minor adjustments that are currently being considered, should protect properly constructed new homes from excessive levels of earthquake damage. However, if a building does not comply with the code, its earthquake resistance may be severely affected.

Building owners are ultimately responsible for complying with codes, yet they generally rely on designers, builders, and building officials to meet them. Local government building officials are responsible for enforcing the building code provisions through plan review and construction in-

CONVENTIONAL CONSTRUCTION

There is an important distinction between conventional light-frame construction ("conventional construction") and most other buildings. Conventional light-frame construction includes light wood-frame buildings of not more than two stories and a basement with four or fewer dwelling units and covers almost all single-family and many multifamily residences. Though conventional buildings, like other structures, are required to be built according to code, they do not need to be designed by an engineer or architect who is trained to calculate earthquake forces and to design lateral force resisting systems. Plans can be drawn by anyone: owners, building contractors, or designers.

spection. For conventional construction, this is meant to ensure that the plans meet the prescriptive requirements of the code and to ensure that builders adhere to the plans, use appropriate materials, and follow accepted practice during construction. Though many building departments have tried to get by with limited reviews of residential construction, "spot checks" by building inspectors clearly do not provide sufficient assurance or reliability that new construction will comply with the code and provide adequate seismic safety.

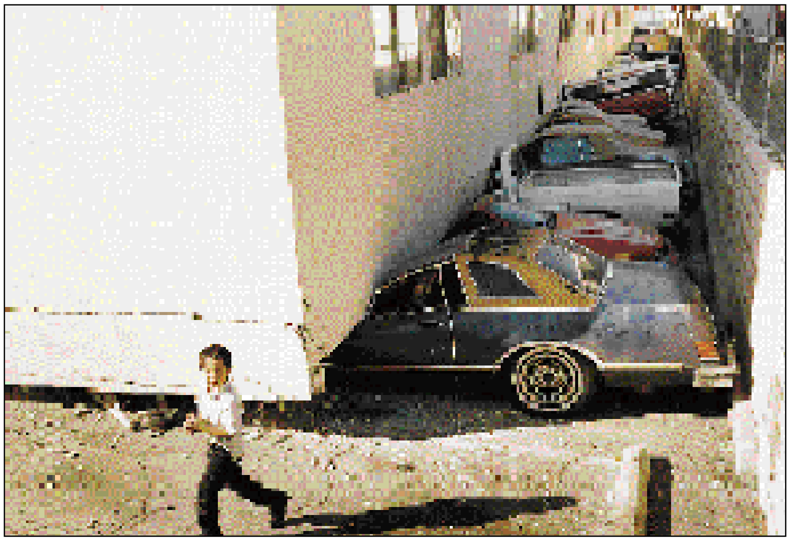
A number of quality concerns surfaced in the aftermath of the Northridge earthquake. Although statistically rigorous data are not available to establish even rough percentages of damage resulting from a lack of code conformance, there is ample evidence that failure to follow code requirements in design and lax plan review, construction inspection, and shoddy construction resulted in significant damage in conventional homes. Improperly installed wire mesh that underlay rather than being embedded in stucco, overdriven nails in plywood, nails placed too close to the plywood edges, undersized nails, oversized bolt holes, and improperly placed foundation anchor bolts are examples.

Controlling earthquake damage depends on the integrity and continuity of the building elements that resist shaking. Braced wall panels intended to resist lateral forces generated during earthquakes can be identified on the plans by the owner, contractor, or designer so their integrity can be ensured. The Commission believes that steps to focus on the quality and integrity of braced wall panels will result in improved performance. Requiring builders to designate them on plans, the plan checker to check them, and the construction inspector to inspect each panel will go a long way to improving seismic performance.

Although public K-14 schools are not conventional construction since they are engineered structures designed by registered professionals, a noticeably higher level of performance is achieved because of their enhanced quality of construction. The dramatic differences between public schools and most other classes of buildings is in the plan review and amount of inspection and review during construction. Relatively few of the quality problems that were seen in damaged conventional construction were seen in public schools following the Northridge earthquake.

Figure 44. Older homes with horizontal wood siding are particularly vulnerable to damage if they are not securely fastened to a proper foundation.

Although improvements in the code and in quality control will reduce the vulnerability of new homes, without effective retrofit programs many existing homes will remain vulnerable. Many homes that were seismically retrofitted before the Northridge earthquake suffered significantly less damage than neighboring homes. Efforts to anchor walls to foundations and brace cripple



Otero, Los Angeles Times

Figure 45. Older apartments like this with tuck-under parking collapsed because they were poorly braced.

walls in crawl spaces below first floors seemed to pay off. Cost-effective retrofit programs with information on what should be done coupled with incentives to accomplish the retrofits are essential to any strategy to reduce the vulnerability of older single-family homes to earthquake damage.

Recommendations

The Commission recommends that:

- CBSC amend the administrative portions of the codes to require persons drawing plans for conventional light-frame construction to clearly identify on the building's plans all braced wall lines, wall panels, and their connections.
- Plan checkers be required to indicate that the braced wall lines and panels meet the requirements of the code, and construction inspectors be required to conduct an inspection to ensure that seismic elements are constructed in accordance with the plans and the building code.
- Inspectors receive special training, continuing education, and certification in the basic concepts of structural design in lowrise buildings, the identification and importance of key seismic elements, and the proper installation of materials, hardware, and devices used to provide seismic resistance.
- Banks and insurance companies create incentives to encourage seismic retrofit by offering lower rates on homes that have been retrofitted.

The features that make homes more attractive and functional—steeply sloping lots, second stories, split levels, high ceilings, sliding glass doors, and large windows—also increase vulnerability to earthquake damage.

The Commission is not recommending that builders, plan checkers, and inspectors of single-family dwellings and other conventional light-frame construction do considerably more but that they do it more carefully. Relatively simple changes in current practice will not increase costs in any substantial way, but improving the quality of plans, plan review, construction, and inspection are far more cost-effective ways to improve a building's earthquake performance than across-the-board requirements for increases in the strength of buildings.

Other Wood-Frame Buildings

The vast majority of buildings subjected to the earthquake were of wood-frame construction. As a class, they generally withstood the earthquake without collapse and for the most part without extensive structural damage. However, a subset of wood-frame structures—multistory buildings with "soft," or inadequately braced, lower stories (generally resulting from inadequate amounts of solid wall to resist earthquake motion)—suffered many failures. The collapse of the three-story Northridge Meadows apartment building resulted in the loss of 16 lives.

In the City of Los Angeles alone, over 17,400 multifamily units were vacated, and 13,600 units suffered major damage in excess of $10,000 each. As of September 1994, 210 apartment buildings and 43 condominiums remained vacant in 17 "ghost towns" scattered throughout the city, and 27 buildings with 475 units had been demolished, according to the City of Los Angeles' Department of Housing (LAHD, 1994). The estimated direct loss in single-family and multifamily housing in the City of Los Angeles alone exceeded $1.15 billion as of November 1994. This damage triggered over 200,000 Small Business Administration loan applications, of which only 55 percent had been approved.

Many of these structures experienced either collapse of the first story or horizontal deflections serious enough to preclude economical repair

(figures 45 and 46). There was extensive cracking of interior wall finishes and exterior plaster or stucco on wood-frame structures throughout the area. In many buildings, these finish materials also served as structural elements for the resistance of lateral forces, so the damage not only caused cosmetic distress but compromised the seismic resistance of the structure. When a stucco wall is erected, it is backed with a wire mesh over building paper attached to wood stud framing. In many cases, wire mesh was improperly installed, so tight to the building paper that the stucco could not bond to the wire. This problem can be addressed by enhanced quality control and education of contractors, stucco installers, and inspectors.

> Prior to the Northridge earthquake, many multifamily rental property owners had already been overleveraged due in part to Los Angeles' weak rental market. The earthquake severely aggravated financial problems for owners already suffering from declining income and high debt, compounded by the fact that many had no insurance. Hence, with many buildings being damaged and/or vacated, property owners simply do not have the cash flow to meet their continuing obligation toward mortgage payments and taxes (LAHD, 1994).

Many multifamily buildings that were safe to occupy and not significantly damaged structurally still needed repairs. Nonstructural damage was much more extensive—and expensive to repair—than most people would have anticipated. However, the Commission believes that, since occupancy was not interrupted for excessive periods of time and repairs did not have to commence immediately, this level of damage, though a hardship to many, was an acceptable loss.

California's cities and counties have many of the most qualified building departments in the world. Enforcement of design requirements for wood-frame buildings by governmental agencies has increased over the years. However, observations after the Northridge earthquake, as well as recent litigation regarding residential construction defects in California, reveal that many of the requirements of the building codes are being

Los Angeles Times

Figure 46. Damage to apartments caused more life and housing losses than other building types in this earthquake.

overlooked or inadequately enforced. Features and requirements of the approved plans are not being followed consistently in the construction process. This lack of code compliance is especially significant as it relates to the requirements for the lateral force resisting systems. Substitution of smaller nails and missing or poorly installed structural hardware such as straps, anchor bolts, and holdown devices were found in post-construction inspections. In a 1993 survey of residential and commercial wood construction, G. G. Schierle found that 17 of 28 seismic elements surveyed were missing or flawed in 40 percent of his 135 surveyed buildings. He emphasized, "It is alarming that key items to resist seismic force are among those most frequently missing or flawed" (Schierle, 1993).

A clear public policy statement on acceptable levels of risk in dwellings has never been made in California by the Legislature or any administrative agency.

Requiring the building designer to observe important details during construction can also improve the reliability of construction. A civil or structural engineer or architect is involved in most multiunit residential projects and virtually all wood-frame commercial and industrial projects but seldom observes construction because it is not typically required by the code and owners are unwilling to pay extra for that service. Moreover, since architects and engineers can be exposed to construction-related disputes

when present on the job site, many design professionals avoid it, so major design and construction substitutions or changes that affect seismic safety are quite often made during construction.

Recommendations

The Commission recommends that:

- CBSC amend the administrative portions of the codes in California to require professionals who are drawing plans for engineered portions of buildings to include and clearly identify on those plans all vertical and horizontal elements of lateral force resisting systems and their connections.
- Local governments initiate efforts to reduce the seismic risk in vulnerable wood-frame buildings such as collapse-risk apartment buildings with "soft" stories.

The Commission is not recommending that builders, plan checkers, and inspectors do more but that they do it more carefully.

Manufactured Housing

As in every recent earthquake, damage to manufactured housing, or mobile homes, was all too common. Numerous studies have found that the performance of mobile homes in California earthquakes is significantly worse than that of conventional wood-frame dwellings.

Because of their light weight, closely spaced walls, and the requirement that they withstand the trailer ride from factory to site without damage, the mobile home itself has been generally regarded by engineers as roughly equivalent in earthquake resistance to conventional wood-frame construction. The federal Department of Housing and Urban Development regulates all manufactured parts of mobile homes above their chassis. With the exception of toppled water heaters and broken gas lines, the seismic performance of mobile homes above their chassis were similar to, if not better than, conventional, single-family wood-frame residences.

The primary seismic weaknesses in mobile homes are the foundations on which the homes are placed. Mobile homes are generally installed on jacks or other supports without regard to wind or seismic forces. These are supposed to be state-regulated and enforced by either the state's Department of Housing and Community Development (HCD) or local governments. However, at the time of the Northridge earthquake, state regulations for mobile home installations were notoriously weak. Although recent legislation applicable to new installations will begin to change this, existing mobile homes remain vulnerable.

Earthquake-activated shut-off valves would probably have prevented some of the fires. However, according to HCD, some of the mobile homes that burned had shifted several feet and severed their gas lines, so individual earthquake-activated gas shut-off valves at the homes would not have prevented these fires. Fires also were started when water heaters toppled and severed their gas lines. Redesigning the gas connections for individual mobile homes to reduce the chance of breakage and installing master shut-off valves that cut off the gas flow at park entrances will reduce the risk of fire. Figure 47 depicts fire damage to mobile homes.

Earthquake resistant bracing (ERB) systems and other techniques can keep mobile homes from shifting off their foundations in earthquakes. A very small number of mobile homes had these bracing systems installed at the time of the Northridge earthquake.

The study of Northridge earthquake mobile home damage by the National Conference of States on Building Codes and Standards found that ERB systems typically kept mobile homes from dropping more than two inches and reduced the horizontal movement. "Damage to

MOBILE HOME DAMAGE	
Number of mobile home parks affected	69
Number of mobile homes in affected parks	9,095
Number of mobile homes in affected parks that fell off jackstands or shifted to the point they required reinstallation	5,412
Number of mobile homes that burned	172
Nearly 60 percent of affected mobile homes fell off their foundations (King, 1994).	

units with ERB systems appeared to be less severe than damage to units that did not have ERB systems and that, consequently, were knocked to the ground" (NCSBCS, 1994). HCD estimated that a typical repair cost for a 24-by-60-foot unit is $17,400. Though relatively low compared to other damage figures, it is significant as mobile homes are extremely low-cost housing units in many areas and often sell for a similar amount. The average damage cost is significantly higher than average costs for ERB systems, which range from $750 to $3,000.

According to HCD's case-study letter report on mobile homes, "The earthquake bracing systems that were in place at the time of the earthquake were systems that would not be approved under recently enhanced standards. Many of these systems were not certified or installed under permit since they predate the permit and inspection requirements. Where homes were fitted with approved systems, the systems performed as designed and prevented the homes from falling to the ground. There was still damage to the contents of the homes that moved laterally. In at least two homes, the earthquake bracing systems caused such serious damage to the steel chassis that the homes were 'totaled' by the insurance companies" (King, 1994). Data on the performance of bracing systems in eight mobile home parks indicate that two of nine systems performed well; the other seven were somewhat helpful but had design inadequacies or were not properly installed.

HCD has been certifying products as complying with an HCD standard for ERB systems since September 1985 and, since January 1990, has performed site inspections when these products are installed. A system is not required for either a newly installed or existing mobile home, but if an owner chooses to purchase one of the approximately 20 different systems available, it must be installed to meet the HCD standard. There is less consensus concerning engineering techniques for mobile home foundations than for wood-frame dwellings. Nevertheless, most engineers would generally agree that "properly designed [ERB systems] can enhance resistance to ground motions, and help to prevent the toppling of manufactured housing units in an earthquake" (Pearson et al., 1993).

MOBILE HOME FIRES

CAUSE OF FIRES	% FIRES
Mobile home shifted several feet and sheared off utility lines where they came out of the ground	76
Gas-fired water heater	17
Miscellaneous or unknown	7

HCD Earthquake Response Report *tabulated these statistics from a survey of mobile home parks in the most heavily shaken area (King, 1994).*

From a life safety standpoint, the poor performance of supports for mobile homes poses a danger greater than wood-frame dwellings, but not as great as some other kinds of construction such as URM buildings. Mobile homes do not collapse when thrown off their supports; occupants receive a violent but not usually life-threatening ride. However, injuries can be expected to be higher in unbraced mobile homes than in conventional wood-frame dwellings because occupants and contents are thrown about, and occasionally the steel jackstands penetrate the floor (see Figure 48). Exit doors in mobile homes can also become stuck closed, creating a serious threat to life in the all-too-likely event of post-earthquake fire.

As of July 1994, Governor Wilson had signed Senate Bill 750 (Roberti) which requires support attachments and tiedowns on new installations. Under this new law, HCD also will develop a standard for connecting concrete block

Figure 47. One hundred seventy-two mobile homes burned in this earthquake. Fires most often started because of severed gas lines.

Scawthorn


McGavin

Figure 48. A steel jackstand pokes up through the floor of a mobile home after it shifted.

supports to the mobile homes. The standards will not require the use of ERB systems but will require tiedowns. HCD adopted emergency regulations in response to Senate Bill 750, but recent emergency regulations do not specify mobile home supports adequate to resist earthquake forces, and HCD is now considering revisions.

In summary, the present mobile home installation policy of the state, though recently enhanced, still accepts more risk for the mobile home than for the conventional wood-frame dwelling. The greatest problem remains with the stock of existing mobile homes, which are still not required to be attached to foundations.

Recommendation

The Commission recommends that:

- Legislation be enacted to require the installation of HCD-approved ERB systems or other systems allowed by SB 750 (Roberti) on existing mobile homes when ownerships are changed or when homes are relocated.

Other recommendations relating to mobile homes, including those dealing with gas shut-off valves, are contained in Chapter IV.

Tilt-up and Reinforced Masonry Buildings

The Northridge earthquake caused significant damage to tilt-up and masonry buildings. Tilt-up damage posed potentially life-threatening collapses that had billion-dollar economic implications. The City of Los Angeles estimates that of the 2,000 tilt-up buildings in the San Fernando Valley, over 350 had moderate structural damage and 200 had severe damage with partial roof collapse and collapse of exterior walls. Heavy damage occurred in areas of strong shaking, including Northridge, Chatsworth, Sylmar, and Sherman Oaks as well as more distant areas such as Newhall and Valencia to the north and Santa Monica to the south. For three to six months after the earthquake, about 500 one-story commercial buildings were vacant and as of November 1, 1994, about 200 remained vacant, creating commercial "ghost towns" largely of tilt-up and reinforced masonry buildings (Figure 49).

Tilt-up buildings serve as light industrial and commercial buildings throughout the state. Southern California alone has an estimated 20,000 tilt-up buildings. The concrete walls in tilt-up buildings are poured on the ground slab and, after curing, are raised—tilted up—to their vertical position. Wood or metal roofs are connected to the walls to brace them and help resist earthquakes. The structural characteristics of tilt-up concrete buildings are similar to those of reinforced masonry-wall construction. Both building types are typically one story, are used primarily for industrial or commercial functions, and have flexible roofs and similar roof-to-wall connections. They also perform very much alike in earthquakes.

The first major test of tilt-up and reinforced masonry construction with flexible roofs was the 1971 San Fernando earthquake. Roof-to-wall connections performed poorly: roofs separated from walls, resulting in numerous instances of partial collapse. This damage was repeated in the 1983 Coalinga and 1987 Whittier earthquakes.

One of the more comprehensive reviews of the San Fernando earthquake damage was the 13 case studies in the 1973 National Oceanic and Atmospheric Administration report. Several of the recommendations that resulted from those case studies are interesting because of their relevance 21 years later:

> The connection between the roof diaphragm and the walls should be improved. Criteria should be developed to provide realistic design force and detail requirements for connecting these elements. Some ductility in the behavior of these connections would be desirable to avoid 'brittle' failures. Details should be subjected to realistic simulated earthquake forces prior to approval.

> Stronger connections between main girders and supporting pilasters are recommended. Improvement in the containment of masonry and concrete at the tops of wall pilasters should be studied.
>
> Continuity should be provided completely across the building by tying together the purlins, joists, or other members in addition to the plywood sheathing (NOAA/EERI, 1973).

Partly as a result of these recommendations, the 1973 UBC contained substantial changes in the requirements for new tilt-up and reinforced masonry construction, which were later extended and clarified in the 1976 UBC (Figure 50).

The 1987 Whittier earthquake confirmed that the new requirements improved building performance. A survey of 121 tilt-ups found that code changes adopted to mitigate wall anchorage and diaphragm continuity problems identified in 1971 appeared to be effective for the level of shaking experienced in the Whittier event but identified new vulnerabilities, partly reflecting changes in construction practice, primarily in the detailing of and connections between tilt-up panels. It was believed that code changes resulting from the 1987 Whittier and 1989 Loma Prieta earthquakes had generally solved those difficulties, but the poor performance of tilt-ups in the Northridge earthquake indicates that additional code changes are needed.

Investigators of the Northridge earthquake damage to tilt-ups point out that:

> While no lives were lost as a result of this performance, the damage sustained by many of the buildings was clearly life-threatening. Economic losses relating directly to repair costs, as well as damaged inventories and business interruption exceeds 1 billion dollars (Hamburger and McCormick, 1994a).

In the Northridge earthquake it was estimated that about 40 percent of the pre-1973/76 and 25 percent of the post-1973/76 tilt-up and masonry buildings had roof connection failures. The Earthquake Engineering Research Institute found evidence that "impact from storage racks appears to have accelerated the separation of wall panels from the roof diaphragm." Retrofitted pre-1976 buildings performed better than their nonretrofitted counterparts (Brooks, 1994; EERI, 1994b).

Tobin

Figure 49. Damage to both new and older tilt-up buildings was widespread.

Many tilt-up failures demonstrate the need for actions recommended earlier in this chapter:

- Many damaged buildings demonstrated poor detailing and installation practices.
- Code requirements may need changes to allow for intense shaking. These changes can be made to the existing code through the normal process.
- The allowable values provided by wood-hardware catalogues and ICBO evaluation reports do not appear to be well coordinated with the strength, toughness, ductility, and displacement requirements assumed by code writers, and, in many cases, qualification tests do not accurately reflect field conditions or dynamic forces, according to the Los Angeles Task Force and others. There are also serious concerns about the test procedures, as well as the safety factors being used by the hardware manufacturers.

EERI

Figure 50. Despite changes to the building code made shortly after the 1971 earthquake, failures occurred in tilt-up buildings.

A potentially more intractable problem is that the displacement or elongation inherent in metal connections may be incompatible with the re-

Schmid

Figure 51. This metal connector stretched, distorted, and eventually caused the wood to split.

mainder of the structural system. Hardware catalogs and ICBO reports generally do not provide information about how connections will stretch or deform under earthquake forces, and there is controversy over how much elongation to allow in proposed code revisions. This is a complicated problem that is inherent in the current system of divided responsibility for the various elements of a building discussed earlier in this chapter. In this case, though hardware engineers are responsible for the seismic safety of connection hardware, building engineers are typically not aware of the limitations assumed by hardware engineers. Similarly, hardware engineers may not realize what design assumptions are made by building engineers. Published evaluation reports for connection hardware are based on proprietary test data submitted to ICBO by manufacturers, which is not generally available to building engineers. To improve this system, closer coordination regarding the requirements for acceptability is needed between code writers, manufacturers, and building code enforcement agencies. Moreover, individual elements need to be tested in the context of the full assembly to get proper values. ICBO should also inform design professionals of the limits and assumptions associated with ICBO's product approvals (Figure 51).

Figure 52. Connections between the roof and floor slabs and the columns failed in this collapsed building.

EERI

The Commission believes that the performance of tilt-up buildings as demonstrated by the Northridge and earlier earthquakes needs to be improved. Tilt-up structures provide a large part of the commercial and light industrial base for California businesses. The threat of widespread economic losses and business and industry disruptions in future earthquakes rivals the threat to life.

Recommendation

The Commission recommends that:

- The ICBO Evaluation Service review the building product evaluation and approval procedures used to establish allowable design values for earthquake resistance.

  In light of the poor performance of many ICBO-approved products in the Northridge earthquake, the ICBO Evaluation Service should make comprehensive recommendations on how to change product approval procedures and to enhance descriptions of the limitations and assumptions of the approvals in ICBO's evaluation reports.

Concrete-Frame Buildings

More than any other building type, concrete-frame buildings pose a threat to life in future earthquakes. The performance of concrete buildings in the Northridge earthquake was essentially a repeat of past earthquakes. The unsatisfactory performance of older concrete-frame buildings has been known for over 25 years. But these buildings are hard to identify and evaluate, and not all older concrete frames pose significant collapse threats.

Nevertheless, the obvious question has to be addressed: why has it taken governments and the real estate, insurance, financing, and building industries so long to do so little about reducing the seismic risk in this type of building? This is an example of the lack of accountability to address seismic safety at all levels of government.

Though there are relatively few of these buildings throughout California, most of them are

large and crowded; just one collapse could cause hundreds of deaths. Extrication of crushed victims will be difficult, time-consuming, and generally futile. Concrete is brittle and easily cracked during earthquakes, but reinforcing steel can make concrete buildings strong enough to withstand earthquakes. However, concrete columns and beams erected before the mid-1970s often lack enough reinforcing steel to keep them from collapsing or being damaged beyond repair during earthquakes (Figure 53). Seismic retrofits range from as little as $5 per square foot to over $45 per square foot of floor area.

During the Northridge earthquake, several concrete-frame buildings collapsed, and many others came precariously close. At a different time of day, several hundred lives could have been lost at the Bullock's department store building in Northridge (figures 34 and 52) or at the Kaiser Medical Office building nearby (Figure 33). In the 1971 San Fernando earthquake, three such buildings collapsed, killing 52 people. Like Northridge, the San Fernando earthquake occurred in the early hours of the morning, which reduced the number of deaths. The state can't rely on being so lucky in the future.

No single agency is responsible for taking steps to reduce this type of risk in a timely manner. In the private sector, the American Concrete Institute has focused on developing building codes for new concrete construction over the past two decades and only recently has made any significant progress in addressing the problems of seismic evaluation and retrofit. Other volunteer efforts like those of SEAOC have likewise made very little progress.

Three recently funded efforts are encouraging but are proceeding at a slow pace, somewhat like the Caltrans bridge retrofit program before the Loma Prieta earthquake. The National Science Foundation has funded the Repair and Rehabilitation Research Program, a unique collaboration between structural engineers and researchers to develop reliable and practical evaluation and retrofit techniques. FEMA has a project to develop Seismic Rehabilitation Guidelines for all types of buildings throughout the United States. Like the


A. Johnson

Figure 53. This office building's exterior cladding affected the way its frame responded to shaking, finally resulting in column failure and demolition. *Inset,* detail.

NSF program, it is designed to meet the needs of the entire country and does not focus primarily on needs for information on specific building types commonly found in California. The Commission has a Seismic Retrofit Practices Improvement Program that is focusing on this building type but is only one-tenth the size of the federal effort.

Recommendation

The Commission recommends that:

- The state continue its support of the Seismic Retrofit Practices Improvement Program but recognize that the pace of this program is slow and is just a small step toward addressing the substantial risk posed by concrete-frame buildings.

Other recommendations in this report will contribute to addressing this issue, in particular assigning more accountability to the CBSC and establishing a Center for Earthquake Risk Reduction.

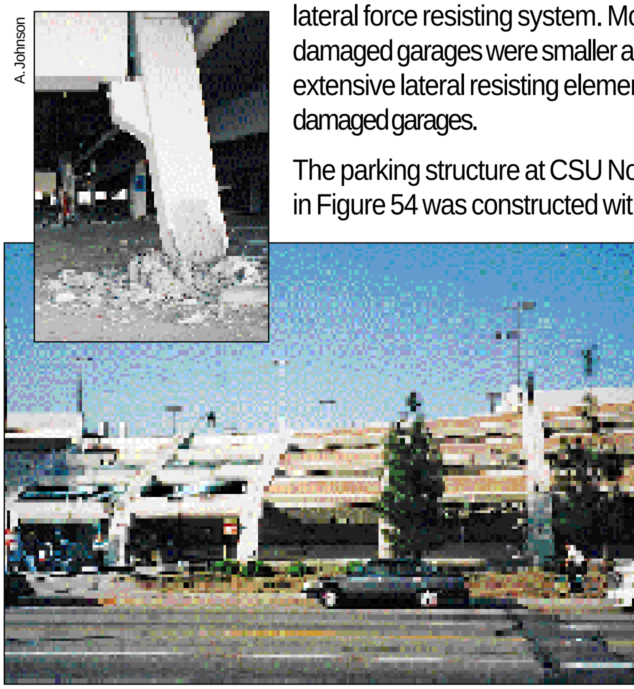
Parking Structures

Parking structures sustained far more damage than expected when compared to other types of structures shaken by the Northridge earthquake. At least 34 parking structures out of approximately 100 in the region sustained sufficient damage to require demolition or significant repair. Almost all the parking structures that suf-

fered significant damage were built after 1960. A common characteristic shared by the partially collapsed garages was the presence of at least some precast concrete elements. Several of the partially collapsed garages appeared to have failed due to inadequate ties between both cast-in-place and precast concrete elements and the lateral force resisting system. Most of the undamaged garages were smaller and had more extensive lateral resisting elements than the damaged garages.

The parking structure at CSU Northridge shown in Figure 54 was constructed with precast concrete "tree" columns and girders. The earthquake forces were resisted by exterior moment frames. The structure deflected under the earthquake forces and the combination of large lateral deformations and vertical load caused crushing in poorly confined, critical interior columns, which were not designed to undergo such deformations. It should be noted that not all parking structures at CSU Northridge suffered such extensive damage.

A. Johnson



EERI

Figure 54. This parking structure's exterior frames leaned over when interior columns failed. *Inset,* detail.

A parking structure in Reseda sustained almost total collapse. This structure was constructed with precast concrete beams, planks, and a poured-in-place topping slab. The columns were poured-in-place concrete. The lateral forces were resisted by walls on three sides, but the structure suffered large displacements on the open side that led to both column failure and loss of support for precast units.

In many cases the exterior columns of the parking structures were damaged because their overall height was reduced by walls or spandrels. The Glendale Fashion Center Garage had precast concrete beams and a poured-in-place topping slab. The lateral forces were resisted by concrete walls. Deep spandrel beams linked short, brittle columns that fractured and a portion of the structure collapsed. The Sherman Oaks Galleria South Garage was another structure where concrete columns and beams were subjected to lateral forces for which they were not designed. Figure 55 shows this type of damage.

Poor performance of structural members was also caused in some instances by the incorrect placement of reinforcing steel. A parking structure in the Universal City area provided such an example. The lateral forces were resisted by concrete walls. The reinforcement of one of the concrete walls was not placed as shown on the structural drawings and the wall failed to resist the lateral forces, resulting in damage from large deformations in the structure.

A number of the seriously damaged above-grade parking structures were designed and constructed through the design-build process described earlier, which may have contributed to their difficulties. However, there were several examples of design-build projects that performed similarly to projects where engineers were hired independently from contractors, so this earthquake was not a clear indictment of the design-build process.

Other evidence does more clearly indicate flaws in the design and construction process. For example, since these structures are often built from components designed by many separate engineering firms, no one engineer is typically responsible for the entire structural system. Failures can and did occur because of this division of responsibility.

The damage to parking structures points out flaws in the quality of design, the codes governing their construction, and construction practices. Improvements in the design of parking structures are needed. The Commission believes that the revisions to the UBC that have already been proposed are needed to improve the performance of parking structures. It is reasonable to infer that a significant percentage of existing parking structures throughout California have

problems similar to those that collapsed in the Northridge earthquake, since these types of structures are common throughout the state.

Steel-Frame Buildings

The biggest surprise in terms of building performance from the Northridge earthquake, at least to the professionals who deal with seismic design regularly, was the poor performance of steel buildings with moment-resisting frames. Steel buildings have long been viewed as among the most reliable structural systems for resisting earthquakes. They are common for modern highrises, not only in California but throughout the world.

The Northridge earthquake caused unprecedented damage in a significant number of these modern buildings, primarily fractures near the beam-to-column welds and in the columns around the beam-to-column connections (see Figure 56). In most cases these failed connections were not readily apparent, as they are typically hidden by fireproofing, ceilings, and walls, but damaged steel buildings have been located both within and outside the areas of strongest shaking.

The damage generally indicates previously unknown limitations on ductile behavior and raises serious questions about current practice for design and construction of such systems. Fortunately none of the failures resulted in building collapse or loss of life. However, since the earthquake shaking was of short duration, it is an open question as to how the damaged buildings would have performed if the shaking had lasted substantially longer or was of stronger intensity.

Extensive connection failures were found in about two dozen buildings, and moderate and minor connection failures have been uncovered in well over 100 steel-frame buildings in the greater Los Angeles area, both within and outside the near-source region of the Northridge earthquake. Many of these buildings are relatively new, constructed from the 1960s to the 1980s, and a few are more than 20 stories high. Approximately 400 other steel-frame buildings have been targeted for inspection by the City of Los Angeles; as inspections continue, the number of affected buildings continues to grow.

Turner

Figure 55. Short columns in this parking structure failed. Modern building codes now require much more reinforcing steel for such short columns.

As of December 1994, research had not yet yielded definitive answers as to root cause, appropriate repair methodology, and possible scope of the problem. Some of the contributing causes of failures suggested are:

- Mechanical properties of the thick steel sections currently in wide use.
- Problems with high-deposition welding electrodes and lack of adherence to American Welding Society procedures.
- Improper or missing details.
- Too few members and moment-resisting connections reduced redundancy and provided too few alternative paths for resisting earthquake forces.
- A level of shaking that exceeded the demands considered in the original designs of the structures.
- Design concepts that put the critical sections at the welded joints.

EERI

Figure 56. Steel-frame connections were unexpectedly cracked.

Considerable change has taken place in the design of steel moment-resisting frames over the years. Driven by a desire for long clear spans, designers have specified ever-larger columns and girders. In the 1970s, column flanges were typically 1.0 inch thick and beam flanges might be 0.75 inch thick. Now the flanges of such columns can be over 4 inches thick and those of the beams nearly 1.5 inches. Only a short time ago these sizes would have been considered unprecedented. The effects of these increases in size on metallurgy, residual stresses, and fracture processes have not been researched adequately.

Both the state and the City of Los Angeles took actions to deal with the problems of fractured moment-frame welds. On April 6, 1994, the Commission issued an advisory that recommended that the "owners of steel-frame buildings who observed damage . . . are encouraged to contact a civil or structural engineer or architect for an opinion regarding the need to selectively investigate critical areas within their buildings" (SSC, 1994g). On May 11, 1994, Los Angeles issued a memorandum on "The Repair of Cracked Moment Connections in Steel-Frame Structures and Requirements for Connections in New Buildings." In it Richard Holquin, assistant chief of the building bureau, pointed out that these were interim measures only and recommended that the plan check engineer notify the owners that "they may wish to wait on the repair work until results of a test program presently underway for this connection are completed." Because of the economic necessities of repair, many owners of damaged steel-frame buildings proceeded with the city's proposed measures or went substantially beyond them. Some owners decided that the need to reoccupy, or more typically, to maintain occupancy, was so great that it was economically desirable to proceed with interim repairs, even if substantial additional work became necessary at a later date.

MOMENT-RESISTING FRAMES

Moment-resisting frames consist of beams and columns welded together at their connections that bend when the ground moves. These frames do not rely on walls or diagonal braces to resist earthquakes.

Ductile moment-resisting frames will yield in a controlled manner at the beams and joints before the columns yield, thus prolonging the stability of the frame and reducing, if not eliminating, the potential for instability, column failure, and collapse.

In contrast, nonductile frames, most commonly used from the 1950s to the early 1970s, were allowed by building codes prior to 1976. These frames are more flexible but may allow columns to fail and become unstable and collapse in moderate to strong shaking.

In cooperation with SEAOC and other professional organizations, the Commission proposed an emergency code change to the UBC. The change requested deletion of the UBC section that contains a prescriptive connection detail for steel special moment-frame beam-to-column connections. On September 14, 1994, the ICBO board of directors approved the Commission's request and deleted the section. On October 24, 1994, CBSC also adopted an emergency change to construction practice for new steel frames in hospitals, public schools, and state-owned buildings. This change will not apply to other types of buildings until the 1994 UBC is adopted by local governments by mid-1995. To avoid more new steel buildings being built to the inadequate 1991 UBC, the Commission amended its advisory to urge that all local governments also take emergency code adoption measures (SSC, 1994g).

A newly formed joint venture by SEAOC, ATC, and the California Universities for Research in Earthquake Engineering has been formed to address this issue. Known as the SAC Joint Venture, it has been funded by FEMA and OES to undertake comprehensive investigations into the failure of steel-frame connections. The question of the extent of hidden damage to other steel-frame buildings that may have been affected by this or other earthquakes is a significant issue. Inspection of the connections is expensive because finishes and fireproofing must be removed, but damaged connections were found in many buildings examined after the Northridge earthquake that did not show any visible signs of structural damage.

Resolving the reasons for failure and finding solutions also should consider the near-source ground-motion effects associated with active faults in urban areas. Though most of the damaged steel buildings were on the periphery or beyond the near-source area, near-source effects may have contributed to some of the failures and may pose significant risks in future earthquakes (see definitions on page 11).

Areas to be investigated simultaneously should include retrofit techniques for existing undamaged but vulnerable buildings and the design of connections for new buildings. There is a vast inventory of steel-frame buildings throughout the state (and the nation) that use details of construction similar to those that failed. Whether or not these buildings have been damaged in other earthquakes, they are at risk from future earthquakes. Once appropriate retrofit and repair methods are identi-

fied, the state should consider providing incentives to encourage owners of buildings to find and repair or retrofit the structures to a condition superior to their original status when leases are renewed or buildings are sold. Without incentive or mandatory inspection and repair/retrofit programs, the expense of dealing with this problem will preclude meaningful progress in reducing earthquake risk.

Unfortunately, very few of the damaged steel buildings were instrumented so that their response to the earthquake could be measured. There were also few free-field instruments in the immediate vicinity of the damaged buildings, so the nature and intensity of the ground shaking to which they were subjected can only be estimated.

Recommendation

The Commission recommends that:

- The state marshal its academic, technological, government, and industry resources to support the SAC Joint Venture to determine how to repair the steel moment-resisting frame connections damaged in the Northridge earthquake.

Seismically Isolated Buildings

There were a few seismically isolated buildings shaken in the Northridge earthquake. They suffered little or no damage, but none was situated close enough to the epicenter to truly test this relatively new approach to earthquake risk reduction. Seismic isolation can be used effectively to reduce the response of buildings to ground motions if isolation systems have suitable force-displacement characteristics that will be maintained over a building's life and if they safely tolerate large displacements while supporting building loads.

However, near-source ground motions, as described in Chapter II, may generate discrete pulses of high ground velocity and displacement to which seismic isolation systems may be particularly vulnerable. If seismic isolation is being considered for future projects, designers should evaluate the effects of near-source motions as well as other unique site effects such as geomorphic and basin-edge effects on seismic isolation systems.

Hospitals

After major urban earthquakes, hospitals can expect to be overwhelmed with the injured. They must be able to withstand the shaking themselves to perform their function of emergency care as well as provide for their existing patients. The 1971 San Fernando earthquake seriously damaged several medical facilities, including the then brand-new Los Angeles County Olive View Hospital. Several of these facilities could not function after the earthquake, and some had to be demolished.

There is a vast inventory of steel-frame buildings throughout the state that use details of construction similar to those that failed.

In response to the recognized need for superior seismic performance by hospitals, and spurred by these spectacular failures, the Legislature enacted the Alfred E. Alquist Hospital Seismic Safety Act (Hospital Act) in 1972. The intent of the act is clear:

> Hospitals, which house patients who have less than the capacity of normally healthy persons to protect themselves, and which must be reasonably capable of providing services to the public after a disaster, shall be designed and constructed to resist forces generated by earthquakes, gravity, and winds.

The Hospital Act proved to be very effective in limiting structural damage in the Northridge earthquake. However, nonstructural damage was extensive. As noted in a draft OSHPD report to its Hospital Building Safety Board:

> Post-1973 hospital buildings and other health care facilities constructed under the requirements of the Seismic Safety Act performed very well with respect to the primary structural systems and with very few problems except for Holy Cross Hospital which has a steel frame and suffered severe structural damage. However, the performance of non-structural parts of the buildings and the equipment and piping systems performed poorly, resulting in extensive damage to the building interiors including flooding, which resulted in the tem-

porary shut down of several post-1973 hospital buildings and the evacuation of patients either fully or partially until extensive repairs and clean up could be effected (OSHPD, 1994a).

The table "Healthcare Buildings Damaged" summarizes the structural and nonstructural performance of hospitals and skilled nursing facilities most heavily impacted by the Northridge earthquake.

Throughout Los Angeles County, 928 patients were relocated because of damage to hospitals (LAFD/EMS, 1994). By comparison, in the 1971 San Fernando earthquake, 17 out of the 23 hospitals in the San Fernando Valley were damaged or destroyed, and 1,327 beds out of 6,751 were lost.

It is not known whether the remaining facilities could have served a larger number of injuries had the earthquake occurred later in the day. The effectiveness and rapidity of emergency measures such as treatment by portable emergency medical centers, use of mutual aid from elsewhere, freeing up capacity by early discharge of patients, cancellation of nonemergency appointments, or transportation of injured patients to more distant undamaged facilities might have been possible, but this has never been tested on a large scale in California.

Only structural damage caused long-term closings. At Holy Cross, for example, nonstructural damage required evacuation on January 17, but the facility was reopened for most services January 24; the trauma and paramedic units reopened February 10. Although nonstructural damage was often very disruptive, repairs and cleanup were typically effected within days. Financial losses to hospitals due to disruption of service are more severe when there is serious structural damage, but the more important loss of ability to serve the community during the hours following the earthquake is more likely to be caused by nonstructural damage (Figure 57).

Performance of Pre-Act Hospitals

Structural damage was greater to pre-act buildings, but many of the two dozen Veterans Administration Sepulveda buildings designed in 1952 experienced only repairable cracking. Good performance in older buildings was associated with reliable types of systems that have not greatly changed over the years (reinforced concrete and reinforced masonry walls) and with regular configurations. Figure 58 illustrates some of the more serious damage in the earthquake to the pre-act St. John's Hospital in Santa Monica.

When the Hospital Act was passed, its authors anticipated that normal replacement of aging facilities would mean that the majority of hospital buildings would be up to the act's standards within a quarter century. However, hospital buildings are not being replaced at the anticipated rate.

Recently enacted SB 1953 (Alquist) requires pre-act hospitals to come into substantial compliance over a 35-year period. Carrying out this new statute will address both structural and nonstructural weaknesses in California acute-care hospitals.

HEALTHCARE BUILDINGS DAMAGED

		NONSTRUCTURAL DAMAGE		STRUCTURAL DAMAGE		
	TOTAL	MAJOR	MINOR	RED-TAGGED (UNSAFE)	YELLOW-TAGGED (RESTRICTED)	GREEN-TAGGED (SAFE)
PRE-ACT BUILDINGS	51	31	20	12	17	22
POST-ACT BUILDINGS	31	7	24	0	1	30

Source: OSHPD, 1994a.

Performance of Post-Act Hospitals

Except for problems with the steel-frame connections at Holy Cross Medical Center and the Henry Mayo Newhall Community Hospital, the structural performance of post-act buildings was excellent. Poor penthouse performance is a concern that can be addressed with minor modifications to OSHPD procedures without major policy changes.

Recent changes to state laws allow OSHPD to post damaged hospitals as safe or unsafe and provide authorization for limited occupancy after disasters, but OSHPD does not have clear authority to prohibit the use of damaged acute-care facilities. Even though the earthquake resistance of these facilities may be severely compromised, OSHPD currently has no clear emergency powers to enforce the directives that are provided on its placards. As a result, hospital owners may keep damaged buildings in operation even if it may be in the best interests of hospital patients, other building occupants, and the general public to redirect acute-care functions to other undamaged facilities nearby. In particular, hospital owners who have previously restored service after a disaster will prefer to avoid adverse public relations that can result when facing a second possible closure if additional damage is discovered.

Nonstructural Damage to Hospitals

When considering the effect of nonstructural damage, it is instructive to look at the three acute-care hospital facilities that had one or more buildings designed and constructed to the Hospital Act, where the disruption was due primarily to nonstructural damage. Holy Cross and Olive View (now named Sylmar) hospitals and six buildings at the Northridge Hospital Medical Center were built to the act. The primary cause of disruption and evacuation at Northridge and Olive View was broken piping and water leakage; at Holy Cross it was damage to mechanical equipment in the heating and air conditioning system. Except as noted, all three suffered (OSHPD, 1994b; McGavin and Patrucco, 1994):

- Sprinkler and other water line breaks and leaks
- HVAC equipment anchorage failures
- Large oxygen tank base failures; leaning tanks
- Toppling of unanchored cabinets and equipment
- Communications failures
- Elevator damage
- Firefighting system failure
- Medical gas failure (except Northridge)
- Backup power outage (except Northridge and Holy Cross)
- Water service outage
- Gas service outage
- Electrical service outage

Though the main hospital buildings at Olive View and Holy Cross were functionally disabled primarily by extensive nonstructural damage, they did suffer some structural damage. OSHPD issued a yellow tag to Holy Cross because it suffered significant structural damage to its steel frame, though the damage was not relevant to the functioning of the hospital in the earthquake's aftermath—it was not discovered until more than a month after the earthquake. Olive View received a yellow tag for structural damage to the penthouse; OSHPD is currently reviewing design procedures for penthouses.

Reitherman

Figure 57. Damage to the heating and ventilation system in this hospital shut it down for a week. Months later, additional structural damage to steel connections was discovered and repaired.

N. Johnson

Figure 58. This older hospital was severely damaged. Lightly reinforced concrete walls lost much of their strength when X cracks formed. *Inset,* detail.

Nonstructural damage in pre-act buildings was significantly greater than in post-act buildings, but it caused widespread, temporary disruptions to essential services in newer hospitals built to Hospital Act requirements.

Water-related components caused the greatest concern. Damage was caused by leakage from sprinkler, domestic water, and chilled water lines; water shortages were caused by the lack of sufficient onsite storage. Twenty-one buildings at healthcare facilities suffered broken nonsprinkler water lines with most of the damage to small lines, less than 2 1/2 inches in diameter, for which bracing is not required by code. Sprinkler line breakage occurred at 35 buildings, all of which was caused by small unbraced branch lines (see Figure 59).

At six facilities (not counting the Veterans Administration's Sepulveda facility), emergency power generator systems failed to operate (Murray, 1994). In some cases, "auxiliary stairwell lighting was not connected to emergency power, necessitating evacuation of patients down totally darkened stairwells" (Snyder, 1994). Emergency power failures also are discussed in Chapter IV.

The fact that two of the largest and newest facilities in the San Fernando Valley—Olive View and Holy Cross—were effectively shut down for the week following the earthquake by nonstructural damage is most troubling and raises issues about whether the Hospital Act's aim to provide functional hospitals is being met. The limited success of the Hospital Act is an example of how simple increases in building code requirements have not necessarily ensured more reliable seismic performance. Many hospital owners have realized this and are departing from conventional code approaches for new hospital designs. OSHPD is now reviewing an ever-growing number and variety of sophisticated designs that attempt to address seismic demands on hospitals that are much more realistic than building code requirements. New and comprehensive design guidelines for achieving seismic performance objectives that are described in earlier sections of this chapter will aid the hospital industry to remain operational after earthquakes.

The Commission believes the performance of nonstructural elements in both pre- and post-act buildings must be improved; otherwise, nonstructural damage will continue to prevent hospitals from functioning at a time when they are most critically needed.

Recommendations

The Commission recommends that:

- Recently enacted legislation requiring the strengthening of nonstructural systems necessary for essential post-earthquake functions be carried out.
- OSHPD, in consultation with the Hospital Building Safety Board, assign the highest priority to quickly retrofitting building components that have proven to be particularly vulnerable and disruptive—sprinkler and other water lines, emergency power, large oxygen tanks, and telephone and radio communications—before requiring retrofits for all the less critical nonstructural items in hospitals.
- OSHPD develop and adopt complete administrative regulations for hospitals, skilled nursing facilities, and intermediate-care facilities and develop and adopt regulations to allow OSHPD to issue minor citations or stop-work orders when violations are observed on construction projects under its jurisdiction.

Elevators

During the 1971 San Fernando earthquake many elevators were severely damaged when their counterweights shook out of their guide rails, endangering the occupants. Consequently, legislation was passed that required that all elevators in California be retrofitted or newly installed to shut down when the elevator is shaken by an earthquake. This shut-down requirement applies to all elevators even though elevators in critical facilities, such as multistory hospitals, are needed for emergency response. Currently, patients must be transported in the stairwells, some of which were dark because of lighting failures immediately following the Northridge earthquake.

Elevators can be designed to withstand earthquake shaking without shutting down unless their counterweights actually do come out of their guide rails. A subcommittee of the California Hospital Building Safety Board is currently examining the feasibility of go-slow elevators. These go-slow elevators would allow hospital staffs to move patients more efficiently after an earthquake without putting the elevator occupants' lives in danger.

Recommendation

The Commission recommends that:

- Legislation be enacted to require at least one go-slow elevator in each wing of all OSHPD-approved multistory healthcare facilities. This legislation should include the retrofitting of one elevator in all existing multistory healthcare facilities.

Communications

Communications among hospitals and emergency services agencies were seriously disrupted in this earthquake. This disruption extended beyond expectable telephone outages to radio links relied on in earthquakes, as summarized in a report prepared for the Commission:

> During the initial roll call of hospitals on the H.E.A.R. (Hospital Emergency Administrative Radio) system beginning immediately after the quake, there was only a 29 percent response and no response from any hospitals in the most impacted area. . . . H.E.A.R. is dependent on land lines and this could have been a primary cause of the disruption. The Reddi-Net computer system was said to have been 90 percent functional by the Hospital Council but again the hospitals in the impacted area did not receive any messages on the system (Cheu, 1994).

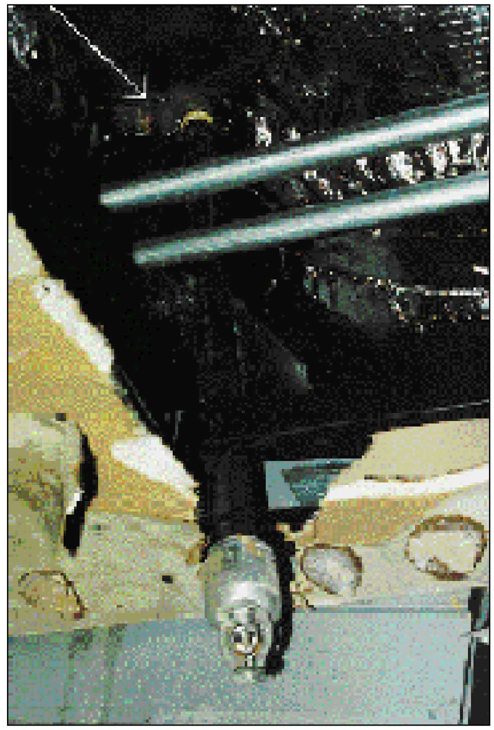

Reitheman

Figure 59. Water from failed sprinkler lines produced costly damage and disruption.

Recommendation

The Commission recommends that:

- Legislation be enacted to require hospitals to install, maintain, and periodically test in realistic exercises redundant emergency communications systems that do not rely on land lines. These systems must connect with emergency responders—police, fire, paramedics, and ambulances—and work within the hospital facility.

Hospital Emergency Plans

Earthquake emergency planning requirements for hospitals are typically guided by the nongovernmental Joint Council on Accreditation of

Healthcare Organizations (JCAHO) through accreditation reviews that a hospital must pass to operate in the United States. JCAHO requires two disaster exercises per year and a written disaster plan that is based on both an internal disaster (typically postulated as a fire) and an external disaster that would generate sudden medical demand (typically a plane crash). Earthquakes do not fit well into the existing JCAHO disaster plans devised for the typical American hospital in that earthquakes are simultaneously an internal and external disaster. For example, Holy Cross or Olive View hospitals experienced water leaks and power and communications problems at the same time that people in the surrounding area were injured and needed treatment. Critiques of hospital earthquake exercises have frequently noted that the exercises are little different from the external disaster (say plane crash) exercises. Elevators are used to transport simulated patients; power is assumed to be normal; no allowance is made for overturned nonstructural elements being nonfunctional; and no provision is made for outside lifelines being unavailable.

A recently passed state law requires hospitals to include all pertinent information regarding the seismic performance of hospital buildings in emergency training, response, and recovery plans (SB 1953, Alquist). However, many hospital disaster training scenarios currently do not address realistic situations where hospitals are damaged by ground shaking and confronted with victims requiring emergency medical aid as well as decisions to evacuate.

Recommendations

The Commission recommends that:

- The Department of Health Services develop regulations in cooperation with JCAHO and OSHPD for recently enacted legislation to mandate that hospitals develop earthquake disaster plans that account for rapid execution of post-earthquake safety evaluations, realistic scenarios of the post-earthquake conditions of their specific buildings, and the availability and reliability of water, power, communication, and other lifeline services.
- OSHPD develop emergency regulations to establish and clarify its authority to post acute-care facilities after disasters and to prohibit the continued use of severely damaged facilities for acute-care purposes.

Essential Services Buildings

California's Essential Services Buildings Seismic Safety Act of 1986 (ESA) regulates the design and construction of new or altered fire stations, police stations, emergency operations centers, California Highway Patrol offices, sheriffs' offices, and emergency communication dispatch centers to increase the likelihood that they will be functional after an earthquake. However, the vast majority of essential services buildings were built prior to the act. It applies only to new buildings and major alterations or additions to existing buildings.

With a few exceptions, essential services buildings functioned effectively after the Northridge earthquake even though some critical components failed to perform at many sites. The state has authorized approximately $45.6 million from a 1990 bond fund for the seismic retrofit of local government essential services buildings.

Fire Stations

Approximately 90 percent of the 105 fire stations were safe for occupancy and were assigned green placards by earthquake damage assessors (Figure 60). Initial assessments of the fire stations indicated several structural and nonstructural problems. Thirty-five stations had door malfunctions; 32 stations had electrical problems; 28 stations had plumbing problems; 19 stations had air conditioning problems; and 18 stations had fallen block walls. Several stations were shut down and later reopened, including one that was shored and then reopened following a one-month closure.

The Los Angeles Fire Department provided a summary of four stations with significant structural damage (LAFD, 1994):

> Fire Station 70 sustained major structural damages to wall and column supports. Estimated preliminary cost of repairs ranges from $650,000 to $750,000.

> Fire Station 78 sustained major structural damage to the northwest exterior corner of the building. The Department of General Services and City engineers have structurally supported the integrity of this facility. The exterior hose tower has moved approximately 2-1/2 to 3 inches.
>
> Fire Station 93 sustained major roof support and pilaster damages with an estimated preliminary repair cost of $80,000.
>
> Old Fire Station 27, destined to serve as the Department's museum, suffered major structural damage, and the building has been declared unsafe to enter. A fence has been erected around the southeast corner at the new Fire Station 27 due to potential danger of collapse, and members have been advised not to park in the adjacent parking lot. The first floor north side of the new Fire Station 27 has been boarded up to deflect falling bricks in the event of aftershocks.

The Los Angeles Fire Department's computerized dispatching system completely failed, and dispatching had to be performed with radio communication for the first day after the earthquake. There was a citywide power outage, and emergency generators also failed. Since most of the older fire stations do not have any emergency generators and some of those in the newer stations that did work were too small to power all electrical systems, many stations had blackouts, and many critical systems were inoperable. As an example, the teletype system that provides each station with a detailed printout of specific fire hydrant locations throughout the affected area became inoperable when the power at individual stations was lost. As the event occurred prior to sunrise and many generators failed, station personnel had to contend with the lack of light.

Inoperable doors on fire stations continue to cause serious emergency-response problems. The large openings in the front of typical fire stations tend to create front walls that are inadequately braced and not stiff enough to prevent large amounts of drift, or movement, during earthquakes. Extensive building displacements can jam the doors. If the doors are down when the earthquake occurs, the fire vehicles can't be driven out until the doors are pried up, removed, or knocked out. In the 1971 San Fernando earthquake, it took 20 minutes for a fire engine at the station located on the site of Olive View Hospital to be extricated. In the 1992 Cape Mendocino earthquake, the door of the Petrolia fire station jammed; the time lost while forcing it open contributed to the destruction of the town's general store, post office, and gas station as an earthquake-caused fire burned out of control. Fire station doors jammed in the 1992 Landers-Big Bear earthquake as well.

The Masonry Society

Figure 60. Most fire stations like this one (Northridge Station 107) sustained little or no structural damage, but some had exit and garage doors that were stuck closed.

Although there were no specific instances reported in the Northridge earthquake in which fires were not fought because equipment could not get out due to jammed doors, measures are needed to correct these deficiencies. The Commission believes that either essential services structures should be engineered to reduce drift so the doors are not affected, or the door assemblies should be designed and specified to withstand large amounts of drift. For new structures a design that reduces drift would be preferred, but for older structures a retrofit of the door assemblies would generally be more cost effective.

Recommendations

The Commission recommends that:

- Legislation be enacted to require state and local agencies to review all pre-1986 essential services facilities for their ability to function after earthquakes and that those found deficient be retrofitted.

- Owners and operators of essential services facilities evaluate and make their emergency communication systems, including their power supplies, earthquake-resistant so that they are not lost during periods of most critical need following earthquakes.
- All new and existing multistory buildings with essential services facilities in upper floors be retrofitted or equipped with at least one go-slow elevator.
- A general obligation bond measure be placed on the 1996 ballot to fund a state and local matching grant program or other funding mechanisms to carry out the recommendations in this section.

City Offices and Emergency Shelters

City halls and buildings designated as emergency shelters are not considered essential services buildings under the ESA. However, all are of considerable importance to local communities immediately following a damaging earthquake and during the recovery period. These critical facilities should be subjected to a higher level of design, plan review, and inspection to ensure their continued and timely occupancy following an earthquake.

Recommendation

The Commission recommends that:

- The ESA be amended to require buildings designated as community shelters and those buildings that serve as the place of business for local governments, such as city halls, be placed within the definition of “essential services buildings.”

Schools

Schools at every educational level suffered some damage in the Northridge earthquake. Since school was not in session, no injuries occurred to students; however, as this section will show, if the timing had been different, there almost certainly would have been injuries, including some chance of severe or deadly ones. School buildings generally fared well structurally. As with other building types, though, other issues were made clear by this earthquake. Discussed in this section will be the differing jurisdictions, responsible authorities, structural and nonstructural standards, and other issues related to the seismic safety of schools in California.

K-14 Schools

Statewide seismic design and construction requirements for K-14—elementary, secondary, and community college—public schools were mandated following the 1933 Long Beach earthquake. Commonly known as the Field Act, these state requirements were extended to the evaluation and retrofit of existing pre-Field Act buildings with the passage of the Garrison Act (1939) and the Greene Act (1967). The lead agency in the state for carrying out these acts is the Division of the State Architect (DSA). DSA reviews the plans and inspects the construction of public schools. The state’s jurisdiction as the building code enforcement agency for schools and the requirements relating to risk reduction of existing pre-act schools does not apply to private schools, the CSU or UC systems.

After earthquakes, DSA acts in an advisory capacity to school districts but does not have authority to post public-school buildings as unsafe or prohibit occupancy. However, after the Northridge earthquake, over 100 public-school campuses were evaluated by structural engineers working under the authority and guidance of DSA, which observed, “No catastrophic collapses were reported of any public-school buildings. Thus, the goals of the regulations and the Field Act were achieved” (DSA, 1994b). Dr. Sid Thompson, Superintendent of Schools for the Los Angeles Unified School District, stated in testimony before the Commission, “I believe in the Field Act. I think that if we hadn’t had the Field Act, it would have been a catastrophe.”

The Commission believes that public-school buildings, even those built to older codes, performed well in the Northridge earthquake. There was no partial or complete collapse of a public school. No major structural elements such as beams or columns fell; most structural damage could be repaired; and buildings could typically

be restored to their previous resisting capacity. This can be attributed to high-quality design, inspection, plan checking, and construction. However, there was enough damage at 127 school campuses in 45 school districts to require damage surveys using the ATC-20 Rapid Evaluation Procedures. As a result of the surveys, 24 buildings were rated unsafe (red tag); 82 were rated limited entry (yellow); all remaining buildings were rated safe to occupy (green). A review of the reports indicates that the engineers had rated the basic structures conservatively. With the exception of some portable buildings and lunch shelters, most structures rated as unsafe were not actually in danger of collapse.

The basic goal of the state's public-school seismic construction regulations is stated in Title 24:

> School buildings constructed pursuant to these regulations are expected to resist earthquake forces generated by major earthquakes of the intensity and severity of the strongest experienced in California without catastrophic collapse, but may experience some repairable architectural or structural damage.

As pointed out in the DSA report (DSA, 1994b) on school performance in the Northridge earthquake and in a private survey (McGavin, 1994), damage can be summarized under a few headings that serve as the basis for risk-reduction measures:

- School buildings constructed before 1976
- Portable or relocatable buildings
- Covered walkways, lunch shelters, and canopies
- Nonstructural falling hazards

Pre-1976 School Buildings

Kennedy High School's administration and gymnasium buildings are unrepairable because of structural damage. The Van Gogh Elementary School is unrepairable because of ground ruptures across the site. Several buildings on the William S. Hart High School campus have been or will be demolished. However, these are extreme cases. Although a vast public-school building inventory was severely shaken by this earthquake, all other buildings suffered much smaller amounts of repairable damage.

It is difficult to summarize the most typical kinds of failures or to make generalizations. There were cracks in walls, spalling of concrete columns at beam-column joints, and cracks in floors, particularly on-grade slabs. This typical structural damage was to be expected from force levels caused by intense shaking. The major portion of the damage was in structures constructed to pre-1976 building regulations, although statistics on performance are not conclusive since the heavily shaken area did not have major school construction in more recent times. An example of typical structural damage is shown in Figure 61.

Community Colleges

The earthquake affected three community colleges (College of the Canyons, Pierce College, and Santa Monica Community College), which experienced damage to light fixtures, suspended ceiling systems, and heavy equipment mounted on roofs. Nonstructural damage at the College of the Canyons totaled over $3.4 million.

The community colleges were administratively part of local school districts until 1968, when legislation created the state community college system and established local community college districts separate from local school districts. However, structures constructed for community colleges are still subject to the design standards and enforcement requirements of the Field Act administered by DSA.

The Legislature recently considered removing community colleges from the Field Act program as a cost-saving measure. The community college chancellor's office argued that community college students are, on average, older than CSU and UC students and thus community colleges should not be held to a higher seismic safety standard. The Commission opposed this legislation largely because neither the community college chancellor's office nor its local districts have properly qualified staffs to take on the responsibilities of building code enforcement. Statewide, 71 community college districts administer a total

of 107 campuses, most of which have no building design professionals. The community college chancellor's office in Sacramento also lacks the capability to provide a centralized quality and safety control system for reliable design and construction. The hiring of private contractors to provide plan checking and inspection services was proposed. However, without adequate technical supervision and an independent system of checks and balances as provided by the Field Act, the community college proposal could have resulted in potentially unreliable construction with long-term loss exposure implications for the state.

McGavin

Figure 61. Damage to a concrete column on a two-story elevated walkway at Patrick Henry Junior High School. Note the failure of the guardrail in the background.

This proposed legislation came close to approval by both houses in December of 1993—a two-percent construction cost savings becomes a tempting option when budgets are shrinking. However, the Commission believes that these cost-cutting exercises are short-sighted, particularly since the state has a long-term investment in its school building stock. In any case, the Northridge earthquake reminded community colleges and the Legislature that there is significant value in ensuring consistent and reliable safety and quality in public-school construction through an independent building code enforcement process. The proposed legislation discussed above has been shelved for the time being.

School Construction Procedures

Like K-12 public schools, community colleges administer construction projects even though some districts may lack the knowledge, experienced personnel, or resources to do it properly. Seeking and evaluating bids are also a concern given the state's complex bidding requirements and the districts' lack of construction management resources. For example, public schools must award contracts to the low bidder even when significant concerns exist regarding the bidder's ability to perform. Lacking the funds to hire a project manager to supervise, review, and inspect the low bidders' work, the community colleges and public school districts are not always equipped to ensure quality work.

Dr. Diane Van Hook, superintendent-president of the Santa Clarita Community College District, testified before the Commission:

> I'm also very concerned about the lowest bid concept. For example, I participated in building a college in another community college district. We knew that the lowest bidder was not a good builder, yet there was nothing we could do about it. We could not get the district that had trouble with the bidder to testify because they were in litigation. There was no way we could disqualify that bidder.

Furthermore, though the Field Act allows DSA to submit potential felony violations to district attorneys for prosecution, only major code violations can justify a felony conviction, so there are inadequate methods of citing contractors for minor violations that do not warrant a lengthy felony process. DSA lacks the ability to stop construction work when major violations are discovered, so even if a district attorney is notified of a violation, construction can proceed.

The overall good performance of public schools does not belie the fact that a relatively small number of older Field Act school buildings still pose a life-threatening risk to students. The state's Field Act regulations have evolved somewhat in tandem with the UBC, so public-school buildings constructed before the mid-1970s include a few potentially hazardous systems such as nonductile concrete frames and above-grade concrete parking structures, as well as tilt-ups.

Recommendations

The Commission recommends that:

- Legislation be enacted to amend the Field Act to require DSA to prepare guidelines and procedures for identifying public-school and community college buildings that have potential collapse risks and to require public-school and community college

districts to evaluate the seismic vulnerability of buildings and school structures built prior to 1976, correct all defects resulting from design, construction, deferred maintenance, or inflexible utility connections during repairs, alterations or additions and retrofit, replace, or phase out of use structures that pose significant risks to life.

- Legislation be enacted to amend the Field Act to authorize DSA to issue minor citations or stop-work orders when violations are observed on public-school construction projects.
- Legislation be enacted to direct DSA and the California Department of Education to determine whether contract bid evaluations and management of school building construction projects are typically executed by properly trained, licensed (where necessary), and qualified personnel within school districts and determine whether the state needs to establish minimum guidelines and personnel qualifications.
- Legislation be enacted to consider the appropriateness and feasibility of requiring prequalification of potential contractors before the submission of bids.

Portable Classroom Buildings

Several portable or relocatable classroom buildings were seriously damaged in the earthquake. Many units had foundation failures where the cripple walls were racked up to eight inches out of plumb. Some fell to the ground. These failures occurred in structures constructed prior to 1976 with wood foundations. Some were poorly maintained and showed evidence of rotting wood and a subsequent loosening of nails intended to resist seismic forces. See Figure 62.

Relocatable classrooms that are owned by public-school districts that do not comply with the Field Act should already have been removed from campuses. However, the State Allocation Board is still issuing a number of waivers for noncomplying owned and leased buildings.

McGavin

Figure 62. Several portable classrooms were seriously damaged after falling from weak or poorly maintained foundations. *Inset,* detail.

Some districts, under the pressures of increasing enrollments and limited budgets, have resorted to using nonconforming portable buildings. Since these units were classified as temporary, with a life of less than three years, they did not require DSA approval. They were sited without permanent foundations designed to resist lateral seismic forces. In the Northridge earthquake, some of these temporary buildings fell off their supports. These failures point out the need for relatively inexpensive and rapidly obtained factory-built school buildings that are installed on adequate foundations.

DSA policies concerning relocatable buildings on school campuses were under review before the Northridge earthquake. DSA developed a four-part program to address these issues. Three of the four parts went into effect via regulations in December 1994. DSA recently proposed legislation with the sponsorship of the Seismic Safety Commission to deem existing trailer-type leased relocatable classrooms built after 1979 to Housing and Community Development (or Department of Housing) standards compliant with the Field Act and suitable for permanent use as long as deficiencies in light fixture and mechanical grill anchorage and foundation bracing are corrected and positive foundation attachments from the frame to the ground are provided. DSA has proposed a number of other changes to accommodate the fact that school districts need to obtain inexpensive units rapidly, while also correcting the present problem of units avoiding Field

Act requirements. They have suggested that the state allow public schools to use federally approved portable classrooms as long as they are adequately attached to their foundations and as long as light fixtures and other nonstructural elements are braced.

Recommendations

The Commission recommends that:

- Legislation be enacted to require public school districts and community colleges to attach portable classrooms to foundations and abate life-threatening nonstructural hazards as proposed by DSA.
- The DSA Field Act Advisory Board work with DSA to develop appropriate legislative language and implementing regulations.

Covered Walkways, Lunch Shelters, and Canopies

These structures normally consist of flat wood-frame roofs supported on steel or concrete vertical cantilever columns embedded in concrete foundations. Some cover large areas or extend for several hundred feet, and all usually connect or abut one or more buildings. The concrete columns are often subject to larger distortions than the adjacent classroom buildings. See figures 61 and 63.

Many of these structures suffered damage at their intersection with other covered walkways or with buildings. The main types of damage were:

- Connection failures caused by wood beams slipping off beam seats
- Connection damage caused by pounding between structures
- Spalling of concrete at the top of columns
- Racking of excessively flexible structures

Figure 63. The lunch shelter at Danube Elementary School leaned over about one foot.

McGavin

Poor maintenance in some instances and less-than-adequate separation joints contributed to the extensive earthquake damage. The lack of maintenance funds from the state and the widespread practice among school districts of deferring the painting, replacement, or repair of leaky roofs or dryrotted or otherwise damaged building elements is a growing contribution to life-threatening situations in public schools.

Recommendations

The Commission recommends that:

- The Legislature develop an adequate funding source for addressing deferred maintenance in public schools.
- Legislation be enacted to direct public schools to review walkways, shelters, and canopies to identify and retrofit those that might endanger students during earthquakes.

Nonstructural and Building Contents Hazards

Nonstructural damage in schools was common. Children certainly would have been hurt or killed by falling elements if the earthquake had happened during school hours.

Nonstructural components were not addressed in the state's regulations for new construction until the mid-1970s, and the San Fernando Valley contained relatively few newer school buildings, so this earthquake did not test the adequacy of current procedures.

According to DSA, light fixtures fell onto desks or to the floor in approximately 100 classrooms. See Figure 64. Cracked partition walls, fallen ceiling tiles, overturned file cabinets, broken window panes, failed light fixture supports, and broken sprinkler water lines were evident in many school buildings located in the strongly shaken area. DSA found many methods for reducing nonstructural damage were quite effec-

tive in this earthquake. The older buildings had proportionally more damage, which suggests that many of these hazards can be reduced by retrofitting existing schools with current methods (see Figure 65).

Had the students been at their desks during the earthquake, injuries could have been minimized if the required "duck, cover, and hold" training worked as intended. However, even these measures would not have prevented all serious injuries. Avoidance of injuries requires dealing with the hazards:

- Light fixtures and other heavy overhead items need backup support or safety wires to attach them to the structure and reduce falling threats.
- Tall file cabinets, bookshelves, library shelving, televisions, and other heavy objects overhead must be anchored to floors or walls.

The voluntary abatement of nonstructural hazards has not proceeded in the face of numerous competing issues and a shortage of funds. DSA and OES, through the Bay Area Regional Earthquake Preparedness Project, published voluntary guidelines in 1990 titled *Identification and Reduction of Nonstructural Earthquake Hazards in California Schools*.

Recommendations

The Commission recommends that:

- All public-school and community college districts evaluate nonstructural elements and abate unacceptable hazards. The Field Act should be amended to require DSA to adopt retroactive, mandatory retrofit standards regarding nonstructural hazards. Public-school and community college districts should be required to abate nonstructural and building contents hazards when undertaking major alterations, additions, renovations, or repairs. In any event, retrofits should be completed no later than 2010.
- A percentage of future school bond proceeds be used to abate life-threatening nonstructural and building contents deficiencies in public schools by 2010.
- Legislation be enacted to require personnel at every school district facilities office to be trained to recognize nonstructural hazards and the effective installation of restraints and anchorages and to require an annual refresher briefing on emergency plans for every administrator and teacher.

McGavin

Figure 64. Falling light fixtures in over 100 classrooms would have posed significant threats to students and teachers had the earthquake occurred during school hours.

Private Schools

The design and construction of privately owned schools is governed by the Private School Building Safety Act of 1986. It requires either an architect or civil or structural engineer to be used for the design of new or altered private schools. The local code enforcement agency must use a structural engineer for design review. The owner must provide for special inspection, and the designer must observe construction.

OES

Figure 65. Though less life-threatening than light fixtures, ceiling tiles were a major property loss that could have been reduced with modern bracing techniques.

State law allows existing collapse-risk private-school buildings to continue to be used for education. Very little is known about the seismic resistance of private schools. They are not subject to the Garrison and Greene acts that required seismic upgrades in the 1960s and 1970s for public schools. In 1983 the Commission mailed a questionnaire to private-school administrators asking for data on buildings containing more than 100 occupants. Though the results were incomplete, they did show that at that time over 21,000 private-school students and staff were housed in buildings built before 1950 (Figure 66).

Private-school trustees and administrators who are responsible for the safety of their students may not be aware of the potential seismic risk

Youssef

Figure 66. Life-threatening structural hazards such as this are still allowed in older private schools throughout California. Most of them have been eliminated in our public schools.

to students in some of their buildings. Nevertheless, because of the consequences of a failure of one of these school buildings, the state should assign a high priority to identifying and abating collapse-risk buildings and life-threatening nonstructural hazards.

Preschools are not covered by either the Field Act or the Private School Building Act. New and altered buildings follow the same building standards and enforcement procedures applicable to nonschool uses. Moreover, there are no requirements to address the risk of collapse-hazard buildings housing preschools or nonstructural hazards. A number of preschools are housed in older buildings that were previously condemned for use as public schools because of seismic risk.

Recommendations

The Commission recommends that:

- Legislation be enacted requiring that at the time of sale or renewal of leases, private-school and preschool buildings housing 25 or more students and constructed before 1986 be evaluated by a structural engineer and that life-threatening earthquake risks, both structural and non-structural, be mitigated.
- Legislation be enacted to require private schools to identify and abate nonstructural and building contents hazards in buildings housing students and in classrooms.

School Emergency Plans

State laws require all public and private schools with more than 50 students to prepare earthquake response plans and to exercise the plans with duck and cover drills each school quarter. Although the laws require each school to designate a person to be responsible, there is no other reporting or performance requirement.

Fortunately, the Northridge earthquake did not test these plans since it occurred outside school hours. However, according to testimony given to the Commission, many of these plans are out of date, and communications equipment, tools, and supplies are not readily available. Not having up-to-date plans or the supplies and equipment they are based on renders this state requirement ineffective. Given the level of life-threatening nonstructural risks and the potential for communitywide disruption after a damaging earthquake, these plans and exercises are essential to the safety of school children.

Recommendations

The Commission recommends that:

- Legislation be enacted to clarify that laws requiring school emergency plans are mandatory and that public-school administrators, boards, and private schools are accountable for compliance.
- Legislation be enacted to direct the California Department of Education to provide up-to-date guidelines specifying the minimal requirements for these plans, including equipment, tools, supplies, and frequency of exercises.

Higher Education Facilities

The performance of state government buildings in the Northridge earthquake can perhaps be best summarized through the experience of its two university systems, the CSU system with 20 campuses and the UC system with nine campuses. The Northridge earthquake affected the CSU campuses at Los Angeles (CSU Los Angeles)—which experienced light damage, mostly nonstructural—and at Northridge (CSU Northridge)—which sustained substantial damage. The earthquake also affected the UC campus at Los Angeles (UCLA).

The two university systems share many statutory similarities with respect to earthquake design provisions. CSU is "exempt from local enforcement of earthquake design requirements but [is] subject to the provisions of the Riley Act seismic design standards set forth in Title 24 California Administrative Code or in the local building codes, whichever is more restrictive." UC is not required "by statute to obtain a local building permit for its buildings or to have seismic design reviewed by local building departments, any State agency, or independent third-party" (McClure, 1984). Both UC and CSU have building code enforcement responsibilities assigned to facilities managers, which means that there is often a potential for conflicts of interest between internal advocates for safety and internal advocates for low budget and quick construction. Unlike public K-14 schools, UC and CSU periodically suffer from the lack of a strong, independent building code enforcement authority. In 1990, the Commission assessed the adequacy and status of seismic safety programs within the UC and CSU systems in *Report to the Governor on Executive Order D-86-90.*

California State University, Northridge

CSU Northridge suffered substantial damage, both structural and nonstructural. The campus is very near the epicenter of the earthquake and was subjected to intense shaking. The damaged structures were both new and old (up to 30 years), and each had somewhat different problems.

- *Parking Structure C* at CSU Northridge was one of the most spectacular failures in the Northridge earthquake. The lateral force resisting system for this structure, completed two years ago, relied on moment-resisting concrete exterior frames to resist earthquake forces in the central eight bays of the exterior perimeter frame in both the north-south and east-west directions. The remaining portions of these perimeter frames were not part of the lateral force resisting system. The columns and beams were precast, and the slabs were poured-in-place, post-tensioned concrete. This structure collapsed on the east side and partially collapsed on the west side; it is a total loss. "The slumping concrete and steel ghost . . . has become the photographic icon for destruction wrought by the temblor," according to a February 11, 1994, report in the *Los Angeles Times.*
- *Science Buildings 1, 2, 3* and *4* are three-story concrete-wall structures. Science 1 and 2 are older structures that were designed by the, then, Office of the State Architect. Each contains a significant number of interior walls. Some of the walls were damaged, but the most significant damage was to the contents, both from the earthquake and the fires that followed. Science 3 and 4 were built in the last four years and though earthquake-resistant walls were used extensively, they were damaged and will have to be repaired.
- *Oviatt Library* was built in 1971; two wings were added in 1990. The original structure is a four-story concrete-wall building with concrete floors and two basement levels below grade. The wings, also four stories with a single basement level below grade, use steel-braced frames to resist lateral forces. The library sustained substantial architectural damage—notably ceiling collapse. Most books fell from their shelves, although many of the bookshelves remained standing, undoubtedly because the shelving had been seismically braced as part of a systemwide program for library shelving. An exterior canopy was damaged at the connections between the older central structure and the additions. The original portion of the structure suffered minor wall cracking but no serious structural damage and was placed back into operation for the fall 1994 semester. However, the newer wings suffered substantial structural damage. Thick steel plates supporting columns at diagonally braced frames cracked. The precast panels were damaged in some locations and one diagonal brace buckled in the east wing. Based on the damage, the building was red-tagged. The retrofit of the

steel-braced frames in the wings will take many months.

- The *Business Administration and Economics*, the *Education,* and *Engineering Addition buildings* were near completion at the time of the earthquake. In each structure, welded-steel moment-frames are used as the lateral force resisting system. These structures sustained damage to moment-frame connections, although nonstructural damage was not severe. Repair of the buildings was completed by the beginning of the fall 1994 semester.

Damage from future major earthquakes could close university campuses for entire terms, or permanently.

CSU made major changes to its procedures for new construction and retrofit of existing buildings after the Loma Prieta earthquake and is not considering significant policy changes as a result of damage from the Northridge earthquake. Administrators and CSU trustees believe the CSU Seismic Review Board, which was formed in 1991, its Seismic Retrofit Program, and the policy described below have been an effective force in helping to prioritize resources. The essence of the CSU trustees' seismic safety policy is as follows:

> It is the policy of the Trustees of the California State University that to the maximum extent feasible by present earthquake engineering practice to acquire, build, maintain, and rehabilitate buildings and other facilities that provide an acceptable level of earthquake safety for students, employees, and the public who occupy these buildings and other facilities at all locations where University operations and activities occur. The standard for new construction is that it meets the life safety and damageability objectives of Title 24 (CBC) provisions; the standard for existing construction is that it provides reasonable life safety protection, consistent with that for typical new buildings. The California State University shall cause to be performed independent technical peer reviews of the seismic aspects of all construction projects from their design initiation, including both new construction and remodeling, for conformance to good seismic resistant practices consistent with this policy. The feasibility of all construction projects shall include seismic safety review and shall be determined by weighing the practical implications and cost of protective measures against the severity and probability of injury resulting from seismic occurrences (CSUCCP, 1993).

CSU, even in the absence of new bond funds, is doing what it can to apply this policy, according to testimony presented to the Commission. The CSU Seismic Review Board is the responsible agent for implementation and conduct of independent peer reviews.

The UCLA Campus

Of the approximately 130 structures on the UCLA campus, 18 were significantly damaged in the Northridge earthquake (Bocchicchio, 1994). Of the 18, seven had been rated as "very poor" and two "poor" in 1993 seismic evaluations; the other nine were rated as less vulnerable. Most of the damage was to nonstructural elements, although there was noteworthy structural damage:

- *Royce Hall*, built in the 1920s, sustained structural damage. It is a popular symbol of the University and houses the main campus auditorium (see Figure 67) and classrooms for a diverse group of academic programs offered by the College of Letters, Arts, and Sciences. This structure had been identified as one of the seven "very poor," or most vulnerable, structures on campus. The structural damage was primarily in the two towers at the entrance. Because these towers stand over the main entrance, it was necessary to close the building. The seismic deficiency of these towers had been noted in a UCLA seismic committee review and a design team was in the process of designing seismic retrofit measures at the time of the earthquake.
- *Dicksen Art Building,* a concrete-wall building, sustained damage to its walls and exterior damage to stucco, concrete, and brick fascia. This building has been identified as requiring additional lateral force resisting elements to prevent future damage or failure.

- The *UCLA Medical Center* suffered minor structural damage including cracked walls and cracked beam column joints, particularly at the second floor of the Neuropsychiatric Institute and Hospital. There was also pounding damage between many of the older structures.

Many of the older buildings sustained damage to URM and hollow clay tile partitions. These partitions are seldom part of the formal lateral force resisting system, but they do resist some of the force and provide much of the damping for the building.

UC administrators are not contemplating significant changes in campus policies as a result of the Northridge earthquake. An informal effort is being made by the office of the president to review recent designs to determine whether they include details and concepts similar to those that were the source of damage in the earthquake. If they do, the engineer is asked to explain how the proposed design will provide the desired performance. UC believes its first priority for retrofitting must be to address the buildings known to pose significant life-threatening risks.

UC and CSU Seismic Safety Programs

The UC and CSU building code enforcement systems lack the independence and consistency provided by the DSA for other public schools. The Commission periodically learns of compromises and priority adjustments affecting seismic safety on UC and CSU campuses that indicate that lower levels of seismic safety are still tolerated by the state in its higher education facilities.

However, with the exception of the inherent lack of independence in the UC and CSU building code enforcement process, the gap in seismic safety between the Field Act and the UC and CSU systems has narrowed in recent years because of substantial and very encouraging improvements within the systems.

Survival of Academic Programs

The extensive damage to the CSU Northridge campus illustrated how buildings can protect life safety and yet still be hard-pressed to restore academic and research programs. Though CSU Northridge demonstrated how to improvise and reopen quickly, it wasn't easy; damage from future major earthquakes could close university campuses for entire terms, or permanently. The experience of the near closure of Stanford University after the 1989 Loma Prieta earthquake reinforces this clear threat to academic programs. Given the location of many of our campuses near major faults, additional attention is needed to deal with this threat.


Sabol

Figure 67. Large sections of a heavy plaster ceiling came down in Royce Hall. At another time of day, injuries and possibly deaths would have resulted.

Recommendations

The Commission recommends that:

- The Governor direct UC and CSU to require each campus facilities manager to determine key buildings and academic functions needed to restore key educational and research programs after earthquakes in addition to life safety concerns that must continue to be the first priority of campus retrofit programs. Earthquake response plans should be established to redirect or restore such critical academic and research functions in a timely manner for realistic earthquake scenarios. The UC and the CSU systems must review the pacing and priorities of their seismic retrofit programs, including nonstructural risk-reduction efforts, to ensure that they will be capable of resuming critical educational and research programs after major earthquakes in a timely manner.
- The Governor direct UC and CSU to establish the goal that all life-threatening structural

and nonstructural seismic hazards in UC and CSU buildings be retrofitted by the year 2005.

- UC and CSU prepare a capital budget plan that would allow completion of seismic retrofitting of all university buildings that pose unacceptably high seismic life safety risks by the year 2005.
- Legislation be enacted to require UC and CSU to adopt guidelines that trigger the seismic retrofit of all hazardous, life-threatening university buildings upon major alterations, reoccupancies, additions, renovations, or repairs.
- DSA complete its effort to develop building seismic retrofit guidelines in cooperation and concurrence with UC, CSU, and other interested organizations by May 1995.
- The Governor direct to the UC Board of Regents and the Legislature to enact new laws to ensure that UC and CSU abide by the minimum seismic design standards and enforcement practices of Title 24, including independent peer review, thorough plan checking, field inspection, and the monitoring of construction by designers for all new, remodel, and retrofit projects.
- The university systems adopt stop-work and citation authority for their code enforcement personnel to reduce minor violations of and enhance compliance with Title 24.
- The Legislature provide sufficient funds for the seismic retrofit of UC and CSU buildings by the year 2005.
- Legislation be enacted to approve the use of program-based budgeting for state seismic retrofit programs as opposed to the current project-phased budgeting that requires delays and added costs due to multiple legislative approvals of each project.

CHAPTER IV

Achieving Seismic Safety in Lifelines

Lifeline network systems—water supply, electric power, transportation, natural gas, and communications—provide critical services to all of us. When these systems are damaged in a disaster, the safety and livelihood of people in affected communities are imperiled directly.

The Northridge earthquake caused failures in all types of lifelines. A number of freeway bridges collapsed, crippling transportation for months after the event. Broken pipelines and equipment deprived utility customers of gas for heating and cooking; water supplies were cut or contaminated. Many emergency power systems were inadequate. Difficulties with communication systems hampered emergency response immediately after the event—when they were most needed.

Lifeline systems are, in many ways, more vulnerable than buildings or other structures. Because a system is typically spread over a large area, it is susceptible to a wide range of earthquake hazards. Different parts of the system can experience very different levels of shaking or ground deformation in the same event. The performance of a system is tied to the weakest of its hundreds or thousands of components. In addition, because many lifelines are buried, damage is difficult to detect and repair, particularly when several components of the same system are damaged.

Seib, Los Angeles Times

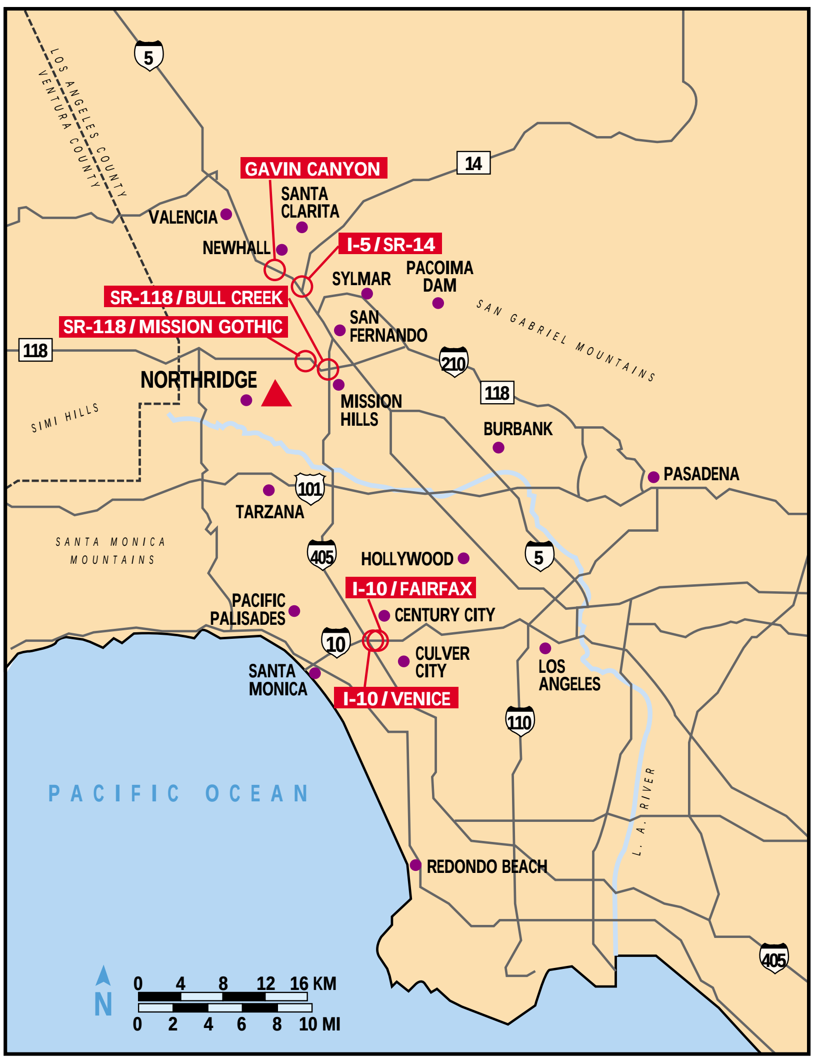
Roadbed sections of part of Interstate 5 fell off their supports.

The organizations that own and operate lifelines cannot ensure absolute reliability and do not accept responsibility for guaranteeing service during emergencies. Therefore, those who need these services during emergencies must anticipate their temporary loss and take appropriate precautions, including working with utilities to ensure better performance. The Commission believes that state and local agencies and the private sector can take a number of additional actions to improve reliability and reduce the vulnerability of lifelines to earthquakes.

Freeway Bridges

The Northridge earthquake caused the collapse, or partial collapse, of seven freeway bridges; over 250 others were damaged. One life was lost as a result of these failures, and traffic was extensively disrupted for months. The repairs, which were completed very rapidly considering the extent of the damages, cost over $350 million. Shaking as intense as that recorded near the epicenter of the Northridge earthquake will always cause some damage to large freeway structures, but they should not collapse.

Figure 68. Location of collapsed overpasses.



The Caltrans Seismic Advisory Board's report *The Continuing Challenge* sets forth a number of findings and recommendations based on the board's review of the effects of the Northridge earthquake. The Commission concurs with the recommendations of that report.

Performance of Bridges

Caltrans summarized damage to bridge structures from the Northridge earthquake (Housner, 1994):

Collapsed or partially collapsed	7
Major damage	39
Other damage requiring repair	194
Hinges requiring repair or replacement	46

North and South Connector Overcrossings

The interchange of State Route 14 and Interstate 5 (see Figure 68 for locations) was badly damaged in the 1971 San Fernando earthquake, but the two structures that collapsed in the Northridge earthquake, the North and South Connector overcrossings, were designed before 1971. At that time it was believed that improved hinge restrainers would be adequate to prevent collapse. Though they contain some pre-1971 design details, hinge restrainers were added to both bridges. During the Northridge earthquake, brittle shear failures in short stiff columns next to the abutments initiated the collapse of both bridges as shown in Figure 69. After the columns failed in shear and were crushed by the weight of the decks, the decks were pulled from their supporting abutments. As the decks fell, they failed by bending at the adjacent piers. These failures demonstrated that retrofitting such structures with hinge restrainers alone may not be adequate. Retrofitting the single-column piers to

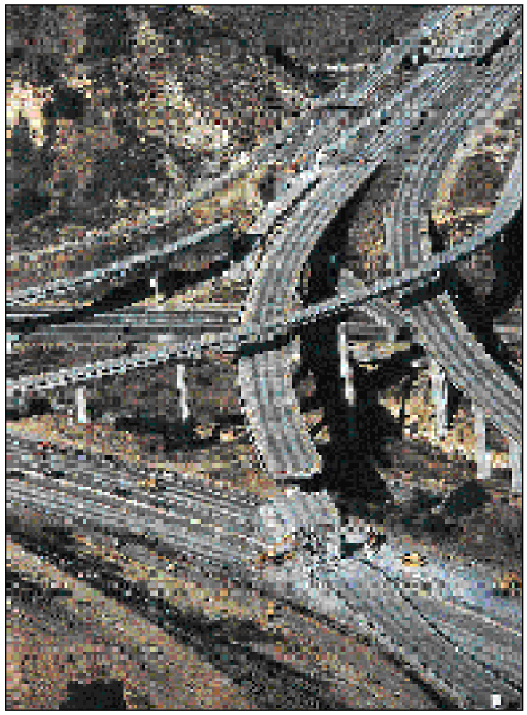
prevent brittle shear, moment, and foundation failures may also be needed. Caltrans has incorporated this observation in the design of both retrofitted and new projects.

Gavin Canyon, Fairfax & Washington, and La Cienega & Venice Undercrossings

Although these three bridges survived the San Fernando earthquake, they had the same deficiencies that allowed bridges to collapse in 1971: short seat widths at abutments and expansion joints and a lack of steel reinforcing ties in the columns. The Gavin Canyon Undercrossing also had an irregular shape that allowed a twisting movement as it shook and short seat widths at midspan expansion joints that made it possible for one end of each of two deck sections to fall off their supports, leading to the collapse shown in Figure 70. The joint restrainers installed in 1974 were not strong enough to prevent the deck sections from falling; had they been stronger, shear failures in the shorter columns would likely have occurred. Shear failure in columns demonstrates that the use of reinforcing steel ties spaced 12 inches apart may be inadequate to confine the core concrete within the main reinforcing steel. Caltrans has integrated this observation in the retrofit program and in the design of new structures.

Mission & Gothic and Bull Creek Canyon Channel Undercrossings

These two bridges on State Route 118 were designed and constructed after the 1971 San Fernando earthquake but before 1980, when Caltrans introduced major design changes. They collapsed because the columns failed in shear. In both cases, the effective lengths of the columns had been shortened; in other words, the columns responded stiffly, as if they were shorter than their actual length. The wide, moderately reinforced column flares of the Mission & Gothic Undercrossing and the channel wall at the Bull Creek Canyon Channel Undercrossing caused these shortening effects, which produced greater shear stresses than had been calculated in design. Since these two bridges had been evaluated by Caltrans as not requiring retrofit, their failures indicate a need to reconsider the criteria for selecting structures for retrofit, which could have prevented these failures.



Tobinn

Figure 69. Two overpass collapses at the I-5/SR-14 interchange were started by failures in short, stiff columns.

Steel-Girder Bridges

Although no steel-girder bridges collapsed during the Northridge earthquake, four bridges of this type, in a three-mile segment of Interstate 5 near the City of Newhall, sustained significant structural damage (Astaneh-Asl et al., 1994). These bridges are the Pico-Lyons Overcrossing, the Santa Clara River Bridge, the Valencia Boulevard Overcrossing, and the Old Road Bridge over the Santa Clara River.

Figure 70. Deck sections fell off their seats at the Gavin Canyon Undercrossing on I-5.

Seible

Seismic Design Specifications

Before the San Fernando earthquake, no California bridge had collapsed because of earthquake shaking. However, the damage to bridge structures during that earthquake made it very clear that many of the approximately 18,000 state, county, and city bridges had deficiencies that made them hazardous and that the 1963 seismic provisions were outdated. Caltrans made major changes to the seismic provisions of its Design Specifications, doubling the 1963 code force for all bridges supported on spread footings and increasing it by a factor of 2.5 for those on pile foundations. Design changes were also implemented to improve:

Shaking as intense as that in the Northridge earthquake will always damage freeways, but they should not collapse.

- *Expansion joints*—increased support seat width and separation restraint at expansion joints to prevent decks from falling.
- *Columns*—increased steel reinforcing tie and size and reduced tie spacing to prevent shear and flexure failures in columns.
- *Column caps*—increased steel reinforcing bars to tie column caps to box-girder decks.
- *Column foundations*—increased anchorage of steel reinforcement in the columns to their foundations.
- *Abutments and wing walls*—increased the strength of abutments and wing walls to resist backfill earth pressures and deck loadings.

In 1975 improvements were made to expansion joint restrainer designs, and in 1977 the Design Specifications incorporated elastic spectra rather than prereduced spectra. Load reduction factors were specified for individual structural components, depending on the toughness of the corresponding components. About 1980 Caltrans introduced the concepts of plastic hinging and shears into the design process. All provisions in the Design Specifications are now being reviewed by the Applied Technology Council (ATC), and Caltrans has already adopted significant changes to improve the seismic design criteria. Recent test results indicate that most of the new design details are effective, although further substantiation is needed.

The Commission believes Caltrans has addressed design standards to incorporate the lessons of past earthquakes and that the current ATC review will result in additional improvements.

Current Performance Criteria

Caltrans has adopted criteria to describe how bridges should perform in earthquakes. Bridges are classified into two categories: *important* bridges and *minimum-performance* bridges. The bridges in each category are expected to satisfy performance requirements when subjected to two levels of earthquake shaking: a *functional-evaluation level* that has a 40 percent probability of being exceeded during the usual lifetime of the bridge, and a *safety-evaluation level* that is based on either the maximum expected earthquake or an earthquake having a return period in the range of 1,000 to 2,000 years. The functional-level motion is less intense; the safety-level motion is less frequent.

A bridge is classified as *important* if one of three conditions is met:

1. The bridge is required to provide secondary life safety, such as access to an emergency facility.
2. Loss of use of the bridge after an earthquake would create a major economic impact.
3. The bridge is designated as critical by a local emergency plan.

The performance requirements for *important* bridges are:

- The bridge may have minimal damage when subjected to functional-level shaking, but it must be able to be restored to service immediately.
- The bridge's damage must be repairable when it is subjected to the safety-level shaking, and it must be able to be restored to service immediately.

The performance requirements for *minimum-performance* bridges—all bridges not designated as *important*—are:

- When the bridge is subjected to the functional-level shaking, the damage must be repairable, and it must be able to be restored to service immediately.
- The risk of collapse is minimal when the bridge is subjected to the safety-level shaking, but the bridge may be closed for repairs, with only limited access, for a few days after the earthquake; full service may not be restored for months.

The Commission agrees that these performance levels and earthquake criteria are appropriate.

Retrofit Programs

Although the first-generation hinge restrainers installed at expansion joints following the 1971 San Fernando earthquake were deficient, those of current design have been effective in preventing the unseating of girders at their hinge seats. However, effective hinge restrainers often permit higher deck-level seismic forces, causing shear and flexural failures in the piers and failures in their foundations. Thus, piers and foundations may have to be strengthened for hinge restrainers to be effective.

The Northridge earthquake tested the column retrofit effort. A 1,037-foot-long structure at the junction of Interstate 10 and Interstate 405 is supported by single-column piers that were retrofitted with steel jackets in 1991. It is located only about four miles west of the Interstate 10 freeway structures that collapsed. A peak acceleration of 1.83g was recorded at the deck level, but the bridge did not suffer significant damage.

In all, 24 retrofitted bridges in the region experienced peak ground accelerations greater than 0.5g, and 60 retrofitted bridges in the region experienced peak ground accelerations greater than 0.25g. These bridges performed satisfactorily. The Commission believes that although Caltrans' current program to retrofit single-column-pier bridges was effective in the Northridge earthquake, future earthquakes with similar intensities but much longer durations than the nine-second Northridge event—perhaps up to 60 seconds—will provide much more severe conditions to test the effectiveness of the program.

It is too early to judge the effectiveness of Caltrans' program to retrofit multicolumn-pier bridges. The Commission believes it is important that Caltrans continue to subject these projects to peer review on a case-by-case basis and make full use of laboratory test results.

It is too early to judge the effectiveness of Caltrans' program to retrofit multicolumn bridges.

Priorities

The Commission believes Caltrans should reassess its procedure for setting retrofit priorities and revise it to reflect all key factors affecting vulnerability (such as flared columns and variable soil conditions) and the importance of the structure, or sequence of structures, to the region served. Caltrans had scheduled the retrofit for the North and South Connector overcrossings and the Gavin Canyon, Fairfax & Washington, and La Cienega & Venice undercrossings before the Northridge earthquake, but the work had not yet been done when the event occurred. These failures caused significant disruption to the entire region. In hindsight, the retrofit of these structures should have been a higher priority, reflecting their vulnerability and importance.

Pace of Caltrans Retrofit Programs

The Commission affirms Caltrans' goal to complete the retrofit of state highway structures by the end of 1997. The hinge-restrainer retrofit program for state and local bridges has been completed; the program for single-column-pier bridges is nearly complete; and the initial program for 1,039 multicolumn-pier bridges, now known as Phase I, will be completed by the end of 1995. Phase II, consisting of state-owned bridges evaluated after the Northridge earthquake, is underway with a tentative completion date of 1997. The toll bridge retrofit program has

started. Retrofit of the San Francisco-Oakland Bay Bridge is to be completed by December 1997, but the completion goal for six other toll bridges has not been set. The Commission believes that toll bridges should be accorded the highest priority because of their importance to the regions they serve, the lack of alternative routes, and their vulnerability. Caltrans concurs with this position; the department is pursuing an abbreviated environmental review process for certain toll bridge retrofit projects and is actively investigating ways to accelerate the toll bridge retrofit program. The Commission supports these efforts but believes Caltrans must be given the necessary resources and be held accountable for meeting these deadlines.

Recommendation

The Commission recommends that:

- The toll bridge retrofit program be accelerated because of the critical importance of those structures and that Caltrans' efforts to do so be supported.

Steel or Concrete Girders

Engineers continue to debate whether steel girders are preferable to prestressed concrete-box girders. Commissioner Chang submitted a paper strongly urging the use of steel girders for the repair of damaged bridges and construction of bridges in seismically sensitive areas (SSC, 1994a). Many factors contributed to the damage of bridges, including inadequate seat widths, skew, curved alignments, local soil conditions, and outdated design. The Commission encourages Caltrans to consider all possible performance factors in its retrofitting, repair, and construction of bridges.

Recommendation

The Commission recommends that:

- Caltrans perform seismic performance probabilistic risk assessments of both concrete and steel designs as part of its continuing program of evaluation and improving the seismic safety of bridges.

New Technologies

New technologies and systems such as seismic isolation, energy dissipation, and damping systems can be used on bridges to reduce earthquake forces and motions or to absorb earthquake energy. Use of these systems should be considered and studies completed to evaluate site characteristics affecting the nature of anticipated ground motion and the structural characteristics of each bridge.

Recommendation

The Commission recommends that:

- Caltrans study different types of seismic isolation and damping systems to protect bridge girders and columns from earthquake damage and take into consideration the effects of local soil conditions and near-source ground motion.

Use of Seismic (Base) Isolation

Seismic isolation technology can be used to reduce seismically induced forces in a bridge structure if the isolation system:

- Has suitable force-displacement and damping properties that will be maintained over the life of the structure.
- Will remain stable under the combined static and seismic loadings during the shaking of a safety-evaluation seismic event.
- Can safely tolerate the associated large shear displacements produced in the isolation system.

Since the use of isolation increases the fundamental period of the overall system, peak free-field ground acceleration is no longer critical to the seismic response. However, free-field velocity becomes more critical and, with sufficient increase in period, peak free-field displacement can become the most critical parameter. Because of the sensitivity of seismic-isolated bridges to the longer periods of free-field motion, such isolation should be avoided at very soft sites such as those in the San Francisco area. Additional studies are needed to evaluate the effects of near-source motions on seismic-isolated bridges.

Recommendation

The Commission recommends that:

- Caltrans undertake a study of the effects of near-source motion on seismic-isolated bridges before building or retrofitting any seismic-isolated bridges.

Strong-Motion Instrumentation

Since 1971 Caltrans has been placing strong-motion instruments on bridges as part of the state's Strong Motion Instrumentation Program (SMIP), conducted by the California Division of Mines and Geology. Though none of the seven bridges that collapsed or the 39 that sustained heavy damage during the Northridge earthquake were instrumented, records were obtained on six bridges located within a 115-mile radius of the epicenter and free-field surface motions were recorded by 132 instruments located within a 100-mile radius. If the state-of-the-art of predicting the performance of bridges during earthquakes is to be advanced, it is essential that more bridges be fully instrumented, particularly the toll bridges and other large bridges with complex shapes.

As of June 1994, over 300 strong-motion sensors have been placed on 28 state-highway bridges, including five toll bridges. Additional sensors are now being added to these and other bridges as rapidly as possible. The Phase II three-year instrumentation program is budgeted at $1 million per year (1994-1996 fiscal years). It will place 23-sensor arrays at 12 bridge sites, nine-sensor arrays at 18 sites, additional free-field instruments at previously instrumented bridges, and 42 sensors underground at seven locations. By December 1994, the Golden Gate Bridge and Highway Transportation District will install 79 strong-motion sensors at the Golden Gate Bridge: 70 on the bridge, six underground near the bridge, and three sensors on the ground surface near the bridge. Additional instrumentation is expected to be installed following completion of the retrofit program. The Commission believes that installing and maintaining strong-motion instrumentation is being carried out properly and that the effort must be continued beyond the end of Phase II in 1996.

To ensure satisfactory performance of new bridges during functional-level and safety-level seismic events, more research is needed, particularly experimental. The results of this research will allow the development of more realistic analytical models to assess the seismic performance of complex bridge structures. It is important that the models and associated performance evaluations be made for complete systems, including the interaction between the type of soil and the type of structure. In doing so, realistic free-field ground motions for these events need to be considered on a site-specific basis. Caltrans is encouraged to monitor prestress losses in bridge girders under static and earthquake loading conditions and to measure internal forces in highly redundant bridges, as appropriate, to understand the distribution of effective seismic loads to individual structural members.

To ensure the satisfactory performance of new bridges, more research is needed.

Recommendations

The Commission recommends that:

- The bridge instrumentation program be expanded to install strong-motion instruments, including dynamic strain gauges and load cells on selected strategic bridges.
- Caltrans continue to tie seismic research funding to its capital outlay program rather than the Transportation Planning and Research Act.

Multimodal Transportation Systems

Earthquake damage to major elevated highway structures threatens public safety and causes long-term disruption to the commerce and functioning of the affected region. Alternative transportation systems such as rail, light rail, buses, and ferries provide critical transportation options during the emergency response and recovery periods. The presence of these systems and emergency transportation plans provide emergency managers with important resources to manage the response and recovery effort. Earthquake risk-reduction and risk-management benefits of multimodal transportation systems should be

considered along with the economic and environmental reasons for implementing the state's transportation policies emphasizing multimodal transportation.

Recommendation

The Commission recommends that:

- Multimodal transportation and emergency rerouting issues be considered by Caltrans in all seismic design, planning, and policy decisions.

Railroads

Railroads support California's economy by providing year-round transportation for the public and commerce. Since they might also be called on to play a major role in relief efforts after a major earthquake, their ability to remain operable or at the very least to recover rapidly after a major earthquake is important.

In the Northridge earthquake, a westbound freight train of 29 cars derailed on the Southern Pacific's Coast Line in Northridge. The derailment caused the release of several thousand gallons of sulfuric acid from a tank car and also spilled diesel fuel from a locomotive. The damage was over $600,000, not counting cleanup or damage to freight. No injuries were reported as a result of the spills.

The Public Utilities Commission's (PUC) review of this incident revealed that Southern Pacific had earthquake-response procedures in place, but in this instance the moving train was too close to the epicenter to allow enough warning time. Under more typical situations, when trains are several miles from the epicenter, earthquake warning systems should prevent similar derailments and spills. The PUC's review of railroad earthquake-response programs statewide found that many railroads in California do not have adequate response and risk-reduction programs.

Recommendation

The Commission recommends that:

- The PUC review the earthquake response and risk-reduction programs of California's railroads and adopt regulations, including deadlines, for such programs by December 31, 1995.

  The response program shall include the use of an earthquake-notification system and criteria for operational response (for example, stopping, lowered speeds, inspections). The risk-mitigation program shall include mapping seismic hazards along rail line rights-of-way, evaluating the vulnerability of structures (for example, bridges and tunnels), and retrofitting those subject to failure.

Natural-Gas Supply

The Northridge earthquake caused several significant fires when natural-gas pipelines ruptured and mobile homes and other structures moved. Although these fires produced relatively few injuries and no casualties, the Commission believes the number of fires started by natural-gas ignition during this earthquake should have been lower. The danger from fire following earthquakes is extreme. Had weather conditions been less favorable or firefighters delayed, fires could have caused deaths and billions of dollars of additional losses.

Transmission and Distribution Lines

All reasonable efforts to reduce the potential sources of fire must be considered. Although the gas utilities have significantly upgraded their systems to improve earthquake performance, the long-term improvements have not been completed, and the remaining vulnerabilities await either repair or the next earthquake.

According to Southern California Gas Company (SoCalGas) reports, the Northridge earthquake caused the following pipe failures or leaks:

Steel transmission pipelines	35
Steel distribution pipelines	154
Plastic distribution pipelines	27
Leaks on meter sets	6,461
Leaks on customer facilities	15,021

The Northridge earthquake illustrated once again that pipelines are more likely to rupture in areas of ground deformation and displacement, and pipelines carrying hazardous materials should be routed through areas where significant disruption is less likely whenever possible.

The Northridge earthquake also illustrated, as have previous earthquakes, that modern pipe of steel and other materials performs well even when subjected to intense shaking and moderate levels of ground displacement. Most of the problems in transmission pipe appear to have been related to weld failures in oxyacetylene-welded steel pipe installed before 1932, when welding procedures were inferior to those currently used (O'Rourke and Palmer, 1994). The natural-gas fire on Balboa Boulevard, Figure 71, was from an older pipeline in an area where significant ground deformation occurred; the resulting fire engulfed five nearby homes.

There are a large number of older, vulnerable transmission and distribution pipelines in highly urbanized areas throughout the state. California gas utility companies have programs to replace or strengthen these older pipelines according to priorities that consider seismic vulnerability. The Commission believes that a review of these programs is needed to incorporate new information regarding active faults and the resulting ground motion and deformation expected as well as new mitigation approaches. Older transmission and distribution lines in densely populated neighborhoods, near critical facilities, or near special occupancies such as schools and hospitals should receive the highest priorities for replacement.

According to SoCalGas statistics, as of 1993 there were 3,803 miles of steel transmission pipelines, 26,809 miles of steel distribution mains, and 14,935 miles of medium-density polyethylene distribution pipe. With so many miles of pipeline, breaks during future earthquakes must be anticipated. To minimize the threat of fire, measures must be developed to detect and respond to failures rapidly.

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Figure 71. Fire and flood produced calamity at Balboa Boulevard's ruptured gas and water mains.

Recommendations

The Commission recommends that:

- California utilities accelerate their upgrade and replacement programs to improve the performance of seismically vulnerable gas transmission and distribution lines. Priority should be given to those pipelines in the vicinity of essential facilities, special occupancies, and dense population, and in populated areas with potential ground deformation.
- Emergency response procedures be improved and valves installed in areas where ruptures are more likely so that breaks can be rapidly detected and lines depressurized to reduce the potential for explosions or gas-fed fires.
- The PUC issue recommendations and regulations to ensure improvement in the safety and seismic performance of gas transmission and distribution lines, including implementation schedules and priorities and the use of automatic shut-off valves, as appropriate, by June 30, 1996.

Mobile Home Gas Service

Although the earthquake caused only 54 fires in other types of structures, gas-fed fires destroyed 172 mobile homes. Most of the gas leaks were caused when mobile homes collapsed onto their meter sets or sheared gas connections as they fell or by interior lines rupturing when water heaters

The threat of fire from natural-gas leaks following earthquakes is a substantial risk.

fell. In most cases the gas could not be shut off and continued to feed the fires. Because mobile home parks are particularly vulnerable to fire, the gas service must be easily and rapidly controllable in earthquakes.

Although new mobile home installations are required to meet seismic resistance standards, existing mobile homes are not. Mobile home owners need reliable information on seismic vulnerability and the steps they can take to mitigate their risk. Reducing mobile home seismic vulnerability is also discussed in Chapter III.

Recommendations

The Commission recommends that:

- Automatic gas shut-off valves be mandatory at the service entry point at all mobile home parks in California.
- The PUC conduct hearings and workshops to determine the best method for providing shut-off valves for mobile home parks and appropriate performance standards for such valves and to prepare draft legislation mandating shut-off valves for mobile home parks by September 1, 1995.
- The Department of Housing and Community Development develop and institute an education program for mobile home owners and park managers to encourage and guide installation of seismic bracing for mobile homes, proper bracing for water heaters in mobile homes, and measures to reduce the risk of gas-fed fires in mobile homes and mobile home parks.

Residential Gas Service

There have been relatively few serious fires caused by interior gas leaks in past California earthquakes. Current mitigation techniques for such leaks and fires include anchoring appliances such as water heaters, using flexible connections, and installing fire alarms and sprinkler systems. Although recent building codes have mandated some of these measures, the majority of existing structures and their occupants are not as well protected.

Whether mandatory or voluntary, the use of earthquake-activated gas shut-off valves involves a number of issues including long-term reliability and maintenance, resetting, and cost. Utility customers who have installed them as added safety devices should still anchor appliances and fix structural weaknesses in their buildings.

The Commission believes that the threat of fire from natural-gas leaks following earthquakes is a substantial risk to entire communities. The PUC, gas utilities, and the State Fire Marshal should recommend a course of action to reduce this risk.

Recommendations

The Commission recommends that:

- The PUC sponsor a task force of representatives from the California Utilities Emergency Association (a division of the Office of Emergency Services), utilities, construction, manufacturing, emergency and fire services, and local governments to evaluate the damage data from the Northridge earthquake and other recent earthquakes, define the risks of fire and potential for damage and injury, and review alternative mitigation methods, including the use of earthquake-activated shut-off valves.
- The Division of the State Architect (DSA) review the adequacy of its criteria for earthquake-activated gas shut-off valves and revise them to improve reliability.
- The PUC use the task force results to adopt requirements by June 30, 1996, to reduce natural-gas earthquake risks to an acceptable level and recommend actions for utilities outside the PUC jurisdiction.

Electric Utilities

Over two million electric utility customers in the Los Angeles area lost power and lights at 4:31 on the morning of January 17, 1994. Thanks to redundant transmission and distribution lines and substations, most of these customers had power restored within a few hours, 93 percent within 24 hours, and 99 percent within three days of the event.

Damage to brittle porcelain insulators and bushings in higher-voltage substations was the primary contributor to power outages and the cause of a power surge that affected seven western states and Canada. Although there was much damage, most of the substation equipment performed well, especially the components that were designed to the latest seismic requirements. There was no damage to circuit breakers that met current criteria. Damage to transformer bushings, wave traps, and circuit switches appears to have been caused by either lack of compliance with current criteria or inadequacy of the criteria. An earthquake producing a strong motion of a greater duration might have further reduced system redundancy and extended restoration times. Electric system strengths and weaknesses should be investigated to identify areas for improved risk management.

In earthquakes prior to the Northridge earthquake, high-voltage transmission towers generally performed well, experiencing little or no damage; wind-loading requirements for designing transmission towers also provide protection against strong shaking. However, during the Northridge earthquake, two steel-lattice transmission towers collapsed involving a total of six towers. The towers were located on ridge crests, and the collapses were caused by movement of the footings due to slope failure. Tubular steel towers were also significantly damaged where soft ground conditions amplified motions and permitted displacement of the footings. Site-specific geologic and geotechnical evaluation studies of tower sites along essential transmission lines are needed to reduce the potential for the failure of towers from weaknesses in their foundations.

A number of public and municipal electric and gas utilities in California participate in the Inter-Utility Seismic Working Group to exchange earthquake risk and emergency-planning information and to develop consistent criteria among west coast utilities. In addition, California utilities have undertaken to reduce seismic risks through research and mutual-assistance pacts following earthquakes and other emergencies. These and other utility-initiated activities have resulted in improved seismic standards and performance. The PUC oversees seismic vulnerability reduction programs of the investor-owned utilities; municipally owned utilities such as the Los Angeles Department of Water and Power (DWP) are not within PUC jurisdiction but some, like DWP, participate on a voluntary basis. The Commission believes these types of programs are important in reducing the overall risk from earthquakes in California.

Recommendations

The Commission recommends that:

- Measures be taken by investor-owned and municipal utilities to improve the performance of substations and transmission lines.
- The PUC investigate and evaluate the causes of substation equipment damage and transmission tower failures; the actions utilities are taking to identify the potential for similar failures and improve substation equipment and transmission tower performance; the use of site-specific geologic and geotechnical information for locating and designing utility facilities; and the adequacy of current utility risk-mitigation programs.
- The PUC determine whether mandatory regulations are required for design and location of substation equipment and transmission towers to ensure adequate component and system performance. If regulations are deemed necessary, the PUC should issue such regulations by July 1, 1996.
- Electric utilities not under the jurisdiction of the PUC, such as municipal utilities, cooperate with the PUC and other utilities in reviewing their seismic mitigation programs, and the governing boards of those utilities adopt regulations and practices at least as stringent as those mandated by the PUC for private utilities.

Virtually all aspects of emergency response and coordination depend on power generation.

Emergency Power

Electrical power is critical following an earthquake. Virtually all aspects of emergency response and coordination depend on normal, emergency, or standby power generation.

90 percent of L.A.'s water is imported from northern California and the Colorado River.

Unfortunately, many of the emergency power systems that were called into service following power outages in the Northridge earthquake did not perform their intended function. Most failures were not related to major system components; instead they were due to system logic, interfaces, and operational anomalies. Major mechanical equipment such as engines, turbines, generators, fuel oil tanks, and boilers did not sustain significant damage during the Northridge earthquake; engineered electrical equipment such as transformers, motor control centers, switchgear, and batteries generally functioned well, though cooling system damage resulted in several system failures. Some of the problems encountered were not necessarily related to the earthquake; instances of overheating generators and inoperable transfer switches for connecting loads to emergency services were similar to problems encountered during the 1977 New York blackout (OTA, 1990).

Actions to correct problems with emergency generators could include:

- Establishing service agreements between building managers of critical facilities and vendors of emergency power generators, utilities, or other qualified organizations to provide personnel and equipment for assistance in servicing and repairing emergency power equipment.
- Collaboration between electric utilities, California Utilities Emergency Association, and local jurisdictions to maintain up-to-date information on critical and essential facilities so that these facilities can be given the highest priority for restoration of power after earthquakes.
- Mandatory programs to address proper sizing, design, and installation of emergency power systems; periodic testing and inspection of the generators; and training of building superintendents and facility staffs to maintain and operate their emergency power systems.

Since the electric utilities are not responsible for providing service under emergency conditions, they should inform customers—especially those who operate emergency communications, essential, and hospital services—about the potential loss of electric service following an earthquake. The availability of power to operate critical facilities, lifelines, and communications is an integral part of the ability to respond appropriately during an emergency. Without power, a community's ability to respond effectively is greatly reduced.

The Commission believes that decisive actions are needed in the area of emergency power. For example, hospital representatives testified before the Commission that air quality maintenance district restrictions prevent testing of emergency power generators. They are concerned that the lack of testing affects the reliability of emergency power.

Recommendations

The Commission recommends that:

- Legislation be enacted to require those who own essential communications and emergency services facilities or hospitals to provide for reliable backup power in conjunction with utilities.
- The Air Resources Board investigate claims that local air quality maintenance district restrictions prevent regular testing of emergency generators and resolve any conflicts to allow testing.

Water Supply

As a result of damage caused by the Northridge earthquake, piped drinking water was unavailable in some heavily damaged areas for over two weeks. A number of earthquake-caused fires had to be fought by drafting water from swimming pools or bringing in tanker trucks.

Though 10 percent of the Los Angeles area's water supply comes from local wells, 90 percent is imported from northern California and the Colorado River. The earthquake damaged five major pipelines and severely disrupted water service to Santa Clarita, Simi Valley, and the northern part of the San Fernando Valley.

Breaks in major aqueducts generally occurred at joints. Both steel and concrete pipelines were affected by ground movement or severe ground shaking. Although damaged aqueducts were returned to service within approximately 40 days of the earthquake, some pipelines needed further repairs during the summer to replace the temporary repairs made immediately after the earthquake.

Significant repairs were also required to local water distribution systems after the earthquake. DWP reported approximately 1,400 repairs to mains and services within their system. Simi Valley and Santa Clarita reported an additional 300 repairs to their systems. Most of the distribution pipes affected were either cast-iron pipes with rigid joints (for example, cement- or lead-caulked joints) or steel pipes weakened by corrosion.

There was also extensive damage to older aboveground steel water tanks. In several cases, the entire contents of the tank were lost because of failures of inlet-outlet piping, which generally occurred because the ground shifted under the tanks. Other failures included buckling at the base of tanks, buckling of the shells, and roof damage. Because these storage facilities may represent the only immediate water supply for local systems, special measures must be employed to ensure their integrity after earthquakes (see Figure 72).

Several organizations are addressing the effects of earthquake hazards on water systems, including the California/Nevada Section of the American Water Works Association and California Utilities Emergency Association. Several large water utilities are also part of a California Water and Power Earthquake Engineering Forum, which meets periodically to discuss seismic issues and develop and disseminate regional mitigation strategies.

Large California water districts, which are usually publicly owned, are not regulated to the same degree as are the large investor-owned gas and electric utilities, which must respond to the PUC. The PUC's jurisdiction is limited to privately owned water companies which, while numerous, serve but a small fraction of the state. Many water utilities within the state do have seismic mitigation programs, though they range from sophisticated to rudimentary. For many, identification and mitigation of seismic vulnerabilities is not taking place in a systematic fashion. This is a situation that is a major concern to the Commission. Each water utility should be responsible for developing plans to address seismic vulnerabilities in a systematic manner.

Though the performance of water delivery systems at a regional level was generally acceptable in the Northridge earthquake, the Commission believes that the performance of certain water supply components in this and future earthquakes requires further investigation. In particular, large-diameter welded-steel pipelines with lap-welded joints must be analyzed to determine their threshold of earthquake failure. These pipelines are common within the water transmission system; if widespread damage to them were to occur, the water supply to the southern California region could be seriously disrupted. All the major pipelines bringing water into the Los Angeles basin from northern California cross areas where large damaging earthquakes are expected, and most of them

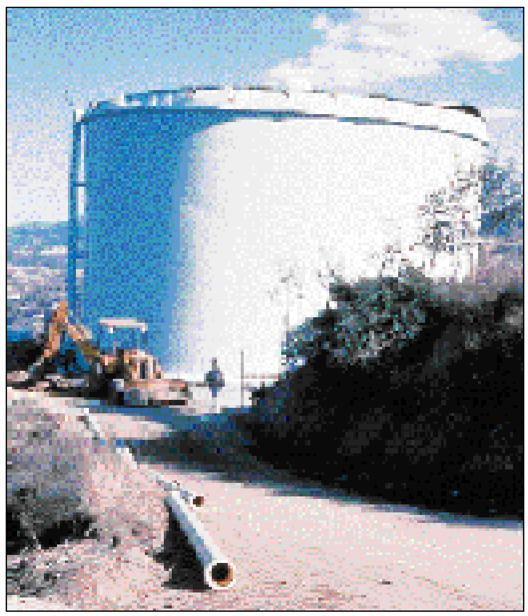

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Figure 72. The walls of this water tank buckled; pipes ruptured and lost 800,000 gallons.

could be put out of service by a single event (Figure 73). Similar situations exist in northern California.

Figure 73. This four-foot-diameter water main under Balboa Boulevard buckled and ruptured when surrounding soils compressed it.

Moreover, a number of water districts rely on single pipelines to bring water to large urban areas. Should those pipelines be damaged significantly in an earthquake, the supply of water could be lost to the areas being served by those lines.

Investor-owned electric and gas utilities cooperate with the PUC and each other in developing mitigation programs for their systems. The mutually supportive work, along with PUC guidance, has been effective.

The Commission believes a state-level agency should encourage and support efforts to improve water supply systems by providing guidance and materials to water districts and by monitoring risk-reduction efforts. The Department of Water Resources is an agency that should provide the needed expertise and leadership.

Recommendations

The Commission recommends that:

- The Department of Water Resources issue a report to all water utilities describing the reasons behind the failures of large-diameter piping, distribution piping, water tanks, and other system components and providing representative risk-mitigation programs to identify and address seismic vulnerabilities.
- Legislation be enacted to require each water utility within California to prepare a seismic mitigation program consisting of a seismic policy and a statement of acceptable levels of risk; a description of potential earthquake damage and system impacts based on likely earthquake scenarios; a priority-based long-term risk-mitigation program; and a commitment to fund the program.

Communications

Many emergency and normal communications systems were disrupted by damage, loss of electrical power, increased call volume, and call convergence into and out of the affected region. The disruption ranged from delayed dial tones to nonfunctioning radio systems. Damage to structural and nonstructural elements of buildings housing communication systems compromised equipment and lines. Because electrical power is needed to operate equipment and dispatch consoles, these facilities need reliable backup power.

The Northridge earthquake's effects on communications systems included:

- *Telephones*—Pacific Bell and General Telephone Electric both experienced difficulties. Though their systems performed well, dial tone delay caused the impression that the telephones were out. The 9-1-1 system was minimally disrupted for a short time. Both companies were able to get facilities back into operation quickly and load-line controls were imposed to give priority users ready access. Commercial land-line companies managed increased call volume and convergence during the disaster by giving priority to predetermined phones used for essential services.
- *Cellular telephones*—cellular phones worked well, but experienced overload. Emergency managers and first responders in the public and private sectors depended on cellular phones immediately after the earthquake. The usefulness and reliability of these systems could have been enhanced by limiting access to cellular phones to essential-services personnel. However, the Federal Communications Commission (FCC) has not established priority access for cellular users similar to that for land-line users.
- *California Office of Emergency Services*—the OASIS system linking Sacramento and Los Alamitos worked as designed.

- *Public safety radio*—radio communication among various police and fire agencies in the affected area was hampered by too few mutual-aid channels, incompatibility of radio systems, and the use of exclusive frequency bands. Moreover, emergency services personnel from other jurisdictions who responded to provide mutual aid often had equipment incompatible with the systems in the affected region. Equipment is available to allow everyone access to all radio bands.
- *Emergency medical communications*—many hospital radios and phones were disrupted, so the Los Angeles Fire Department had to send units to each location to determine its status; paramedic and emergency medical services in the San Fernando Valley and the Northridge areas had major problems; the Los Angeles County Medic Alert Center broke down; the Hospital Emergency Administrative Radio system was inoperable in the area of earthquake impact; Reddi-Net, a computerized system owned by the Hospital Council of Southern California that links 86 hospitals, failed; and mistakes, equipment damage, and lack of training took their toll.

Communications failures during disasters result in breakdowns in service, misunderstandings, lack of information for making decisions, and sometimes loss of life and property. The loss of communications by hospitals and medical providers was a particular problem in this earthquake. The deficiencies of the telephone and radio systems must be reduced to improve emergency response following future earthquakes.

Land-line and cellular communications systems rely on central switching facilities. Although these systems have functioned after recent earthquakes and generally have redundant lines and equipment, their reliability depends on the earthquake resistance of the buildings housing the equipment.

Recommendations

The Commission recommends that:

- The owners of essential services facilities ensure the adequacy of backup power generation systems and assess whether these systems can resist earthquakes.
- The agencies that rely on communication systems during emergency response have reliable redundant backup systems.
- OES explore the possibility of identifying and licensing additional mutual-aid channels in both the VHF and UHF bands for police and fire service use statewide.
- OES continue to place high priority on working with the FCC to address standards for radio equipment that will enhance direct communications between police and fire agencies, including those assigned through mutual aid.
- The PUC work with the cellular industry to facilitate limiting access to cellular phones to essential services after declared disasters.
- The Emergency Medical Services Authority investigate problems with emergency medical communication systems and specify measures to correct inadequacies, including requiring testing of emergency communication systems and training personnel.
- The ESA be amended to require that switch facilities for land lines and cellular communications be located only in buildings constructed or retrofitted to seismic requirements at least as stringent as those found under the Essential Services Buildings Act.
- The Governor petition the FCC to:
  - Provide additional frequency spectra for public safety services and expedite the development of appropriate standards and protocols to facilitate direct communications between systems.
  - Limit access to cellular phone service to essential services after a declared disaster.

Dams

The agency responsible for dam safety in California is the Division of Safety of Dams (DSOD) in the Department of Water Resources. DSOD administers the 1929 Dam Safety Act, which was passed into law after the failure of the St. Francis Dam took more than 450 lives.

The shaking far exceeded the level that the designers of California's older dams even thought possible.

The act applies to all dams meeting certain height and water storage criteria. A total of 1,230 dams fall under state jurisdiction; 116 of these exceed 150 feet in height and 154 have reservoir capacities over 10,000 acre-feet. About 84 percent of the dams are embankment dams; the remainder are concrete. California's 174 federal dams and various other constructions such as levees are not covered by the act, but a modification to the law following the 1963 failure of the Baldwin Hills Reservoir expanded DSOD's jurisdiction to include off-stream water storage facilities.

Following the near-failure of the Lower San Fernando Dam during the 1971 San Fernando earthquake, DSOD undertook a reevaluation of all hydraulic-fill dams under its jurisdiction. This resulted in the placement of operating restrictions on all dams of this type located in highly seismic areas. Los Angeles County also conducted reevaluations of its dams after the San Fernando earthquake, and reservoir levels at several of those dams remain restricted. All the high-hazard dams under DSOD's jurisdiction have been reviewed since 1971.

Immediately following any significant earthquake, DSOD runs a computerized search of all dams within a specified distance of the epicenter, contacts dam owners by telephone, and then dispatches inspection teams to the field. The program predicts those dam sites that experienced horizontal shaking greater than 0.05g. The search after the Northridge earthquake located 108 dams within 47 miles of the epicenter. All but three of these had been inspected four days after the earthquake. The remaining three were visited the following week, and follow-up inspections were made in February and March of dams closest to the epicenter.

Thirteen of the dams had some cracking or movement, but none were judged to be a safety hazard. Eight dams had only minor cracking—six earth dams, one rock-fill dam, and one reinforced-concrete. Only one of the six earth dams is hydraulic-fill, and it is kept empty by DSOD restriction except to serve for flood control.

The most serious effects occurred at Pacoima Dam, a 365-foot-high arch dam located in the San Gabriel Mountains about 11 miles from the epicenter. During the earthquake, the 3,700 acre-foot-capacity reservoir was 27 percent full, and the water surface was 131 feet below the crest. An array of 17 accelerometers at the site recorded motions on the dam and on the canyon walls adjacent to the dam. Peak horizontal accelerations on the abutments ranged from 0.5g at the foot of the dam to over 2.0g on the side walls near the crest. Variations in the abutment motions from the top of the canyon to the bottom and from one side to the other were striking.

Damage visible at the site was consistent with the strong shaking indicated by the accelerograms. Rock slides blocked the access road, damaged the tramway, destroyed many walkways, collapsed the protective cover on the lower spillway chute, and filled the chute with debris. The shotcrete covering the left abutment rock was extensively cracked, and some of the broken shotcrete slid down the canyon walls along with loose underlying rock. The contraction joint between the dam and the concrete thrust block at the left abutment opened by 2 inches at the crest level. The opening decreased to 1/4 of an inch at the bottom of the joint, 60 feet below the crest, and a large crack in the thrust block extended diagonally from the joint to the foundation rock. Survey measurements made after the earthquake indicate one portion of the foundation rock at the left abutment slipped about 2 to 3 inches horizontally and 2 inches down. This movement allowed the contraction joint to open.

Some damage also occurred to the body of Pacoima Dam. Two cracks were visible on the downstream face of the dam from 48 feet below

the crest down to a point 90 feet below the crest. Several cracks were found on the uppermost portion of the dam near the crest, each of which ran diagonally from a shear key corner to either the upstream or downstream face. Post-earthquake measurements indicated that the dam crest was permanently displaced upstream by 2 inches.

The upper 65 feet of Pacoima Dam is most vulnerable to damage. Because the spillway intake is 65 feet below the crest, water would not be released unless a damaging earthquake happened to occur just after a flood. The part of the dam below the upper 65 feet should remain intact in any event.

The peak acceleration at Pacoima Dam was considerably stronger than that currently used in safety assessments of dams in California. Although the dam survived, the earthquake did not test it under stresses caused by a full or nearly full reservoir when the potential for damage in the dam and abutments would be greater. Current engineering capabilities have advanced over the years but are not able to reliably assess such an event or the complicated nature of motion in the canyon of a dam. Improvements in analytical methods, verified by experiments and earthquake shaking measurements, are urgently needed.

The Commission believes that although dam performance in the Northridge earthquake was acceptable, the earthquake was only of moderate magnitude and the duration of the strong shaking was quite short, on the order of nine seconds or less at most sites. However, recorded shaking far exceeded the level that the designers of California's older dams even thought possible. Moreover, a number of recent California earthquakes have also occurred on buried fault systems that were not previously recognized. To its credit, DSOD has been discussing and focusing on buried faults since the Coalinga, Whittier Narrows, and Loma Prieta earthquakes. However, as recommended in chapters II and V, identification and mapping of buried faults must receive a higher priority, and dam regulatory agencies should be involved in that process and use the findings in the reevaluation of existing dams.

DSOD's efforts to regulate the seismic safety of California dams have been successful. They have applied progressive engineering practices to achieve the good performance of dams in past earthquakes and prevent loss of life. However, like other matters of seismic safety in California, DSOD's critical function is underfunded. State funding for dam safety has decreased by 20 percent over the last five years as the number of dams has slowly but significantly increased, and aging dams require more attention. Resulting cutbacks in personnel have reduced the frequency of field inspections and curtailed studies to develop ways of applying research results to dam engineering. The frequency of major earthquakes during the past few years has stretched staff and funding to critical limits.

In its review of the performance of dams in this earthquake, the Commission also examined the question of other dams not under the purview of DSOD. The federal Bureau of Reclamation has responsibility for a number of federal dams in California. Though the bureau has been cooperative in the past, a decrease in its funding leaves a substantial number of its facilities needing repair and upgrading, including Folsom, Friant, and Bradbury (Cachuma) dams. Recent changes in the bureau's mission, which include an abrupt decrease in emphasis on dams and water projects, may well reduce dam safety practices and increase risk. The bureau recently began accepting risk analyses as a substitute for structural repair on potentially deficient dams and using incremental damage study techniques to justify its decisions. It also has not requested needed additional appropriations for its program for safety evaluation of existing dams.

Federal statutes preclude state control over federal agencies performing work related to dams. It may be time to reexamine this situation. Currently, new dams are being designed and constructed by the U.S. Army Corps of Engineers to slightly different standards from

The peak acceleration at Pacoima Dam was considerably stronger than that currently used in safety assessments of dams in California.

state requirements. A few dams, transferred to California sponsors and therefore now under state jurisdiction, have not been accepted by DSOD as meeting California requirements. DSOD is working with the Corps of Engineers and local project sponsors to resolve differences in this area and to ensure state involvement in projects before transfer.

Recommendations

The Commission recommends that:

- The owners of dams be required to fund a dam instrumentation program carried out by the Strong Motion Instrumentation Program at the direction of DSOD.
- DSOD review its current assessment procedures in light of the strong-motion data obtained from the Northridge, Loma Prieta, and Landers earthquakes and assess concrete dams in areas having a likelihood of intense shaking and where the release of water would have significant public safety consequences.
- DSOD be directed to conduct seismic reevaluations and to increase inspection frequency of high-risk dams in zones of high seismic hazard.
- Legislation be enacted to allow DSOD to establish a research program directed towards improving and verifying methods of analyzing the seismic performance of dams.
- The Governor petition the federal government to ensure that all federal dams in California are designed, built, inspected, and repaired to state requirements.

CHAPTER V

Achieving Seismic Safety Through Land Use Planning

The Northridge earthquake showed how land use planning can be used to reduce earthquake damage. Land use planning—community general plans, zoning regulations, and environmental impact reviews—can reduce damage by identifying the seismic hazards caused by geologic conditions as well as vulnerable buildings and lifelines and by instituting measures to avoid or mitigate them. The Commission believes that land use planning policies and laws can and should be far more effective in reducing California's risk from earthquakes than they have been. Management of seismic risk should be a major factor in future land use planning policies and decisions.

Land use planning incorporates local and state government programs that guide private development and public infrastructure investments along a policy course reflecting community values. Taken together, the plans and implementing procedures provide a framework to guide development and redevelopment.

◄ Part of this Pacific Palisades home was destroyed by a landslide.

The safety element must define the extent of seismic hazards in the community and then establish policies and programs to mitigate risk.

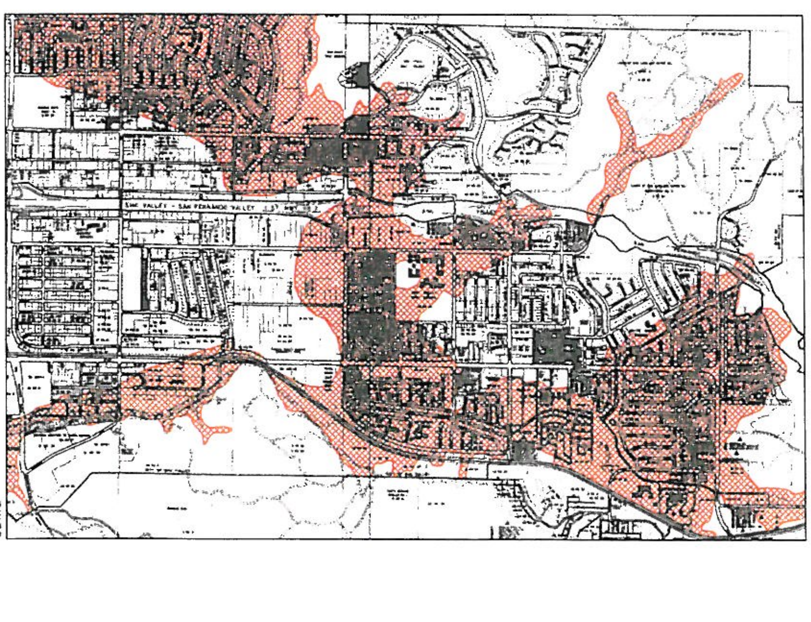
Land use planning can be a strategic tool to recognize opportunities and constraints and to lessen and manage risk by balancing competing values; however, existing laws and guidelines governing these programs are not as effective as they should be. Local governments do not have the information and incentives they need to use land use planning tools effectively. The recommendations in this section, if implemented, would make land use planning a more effective tool in reducing and managing earthquake risk.

Land use planning is a shared responsibility of state and local governments. The state has established various mandates, described below, and is responsible for providing application guidelines and source information. Local governments are responsible for adapting the mandates to local conditions and implementing them on a day-to-day basis. Land use planning can affect seismic safety, especially over the long term, but local governments need better information to reduce earthquake risks.

General Plans and Safety Elements

The state's broadest local land use mandate requires cities and counties to prepare comprehensive, long-term general plans to serve as policy frameworks for local regulations, public and private investments, and intergovernmental coordination. Within these frameworks, local governments review and approve public and private projects according to local zoning, subdivision, and environmental review procedures. Local governments can impose conditions on private projects to minimize the risk of earthquake damage and use regulatory and financing powers to rehabilitate buildings and lifelines that are vulnerable to earthquakes.

Figure 74. Portion of a typical Seismic Hazards Mapping Act map. The orange area is the seismic hazard zone.



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Since the early 1970s, cities and counties have been required to address seismic safety as part of one of the seven required elements of their state-mandated general plans. The safety element must address

> any unreasonable risks associated with the effects of seismically induced surface rupture, ground shaking, ground failure, tsunami, seiche, and dam failure; slope instability leading to mudslides and landslides; subsidence, liquefaction, and other seismic hazards identified pursuant to Chapter 7.8 (commencing with Section 2690) of the Public Resources Code; and other geologic hazards known to the legislative body. . . . (Government Code Section 65302g)

Thus, the safety element must define the extent of seismic hazards in the community and then establish policies and programs to mitigate risk within hazardous areas and prevent or abate structural hazards in new and existing buildings. Since the general plan elements must be integrated and internally consistent, seismic safety policies are carried out through the land use, circulation, housing, and other elements of the plan. Policies outlined in the safety element must also be followed in zoning, subdivision, and public works decisions of local governments.

The background information used to develop the safety element must be thorough and current to serve as a useful basis for decision making. Because collecting original geotechnical information is expensive, most local governments rely heavily on geotechnical information published by the U.S. Geological Survey and the California Division of Mines and Geology (CDMG).

In addition to defining seismic hazards, the safety element should describe the kinds of dam-

age that a community can expect during earthquakes. An understanding of the nature and extent of possible damage provides decision makers with knowledge of how earthquakes affect their communities and what needs to be done. However, the geotechnical information available for a given community for land use planning purposes is often limited or out of date. Effective plans need to reflect the likely presence of seismic hazards such as areas prone to earthquake-induced liquefaction, landslides, subsidence, flooding, and fault rupture. The Seismic Hazards Mapping Act (SHMA), enacted in 1990 (see sidebar), is expected to provide this type of information and to create a process in which developers evaluate the hazard and adopt appropriate mitigation measures. The timely completion of this program is critical to improving the effectiveness of land use plans in California.

Lack of geologic and geotechnical information is a particularly acute problem for local governments; state-of-the-art information in many cases is not available to decision makers and planning staffs or is not available in a form they can use in revising general plans, modifying zoning ordinances, or approving subdivision requests. Moreover, a building designer or utility engineer who lacks information on seismic hazards will not take measures to improve building and lifeline performance. Using the knowledge geologists can provide in land use and building decisions will lead to reduced seismic risk.

Although existing planning law does not require periodic revisions of safety elements to incorporate new seismic information, the SHMA does require published maps to be incorporated in general plans; however, it does not establish deadlines. When the maps and regulations prepared under the SHMA are published, local agencies will require geologic or geotechnical reports before approving projects located in seismic hazard zones mapped by the State Geologist. Reports must be prepared by registered civil engineers or certified engineering geologists and will contain site-specific evaluations of the seismic hazards affecting projects, identify portions of project sites containing seismic hazards, identify any known offsite seismic hazards that could affect the site in the event of earthquakes, and propose mitigation measures.

Another possible source of information regarding likely damage is a planning scenario. Under contract to the Governor's Office of Emergency Services (OES), CDMG has developed seven earthquake planning scenarios intended primarily for emergency response planning. These scenarios depict likely damage patterns in the San Francisco Bay Area and southern California and have been used extensively by emergency response planners, utility companies, and others.

Although these scenarios provide valuable information, they have several limitations for use in developing general plans:

- Each is based on the particular characteristics of a certain earthquake; therefore, its application is limited to planning for a particular event.
- They generally provide only a broad-brush regional perspective, so their usefulness for focused, jurisdiction-specific planning is limited.
- Scenarios have been developed to cover the major urban areas of the state that have experienced the most earthquake damage historically; they are not available for many other areas of California that are susceptible to earthquake damage.
- They focus almost exclusively on public and utility-owned facilities (for example, highways, airports, hospitals, water lines,

THE SEISMIC HAZARDS MAPPING ACT

The SHMA promises to greatly improve the extent and quality of geotechnical information available to local governments, building designers, and utilities. The act directs the State Geologist to prepare maps identifying areas throughout the state that are subject to seismically induced shaking, liquefaction, landslides, ground failure, and other seismic hazards. The California Division of Mines and Geology has begun work on this mapping program (Figure 74 is a portion of a SHMA map), but at the current level of funding, about $1 million per year, it will be decades before maps are complete for most urban areas. Meanwhile, the information available to many local governments to reduce earthquake risks in their communities is not as complete or useful as it should be.

The Federal Emergency Management Agency awarded a $9 million matching grant to fund preparation of 38 maps in Orange, Los Angeles, and Ventura counties over a 2.5-year period.

and electrical transmission lines) for emergency response planning, so they are of limited use in planning for problems associated with damage to private residential, commercial, and industrial facilities.

The Northridge Earthquake

Planners and engineers from eight jurisdictions that had structures damaged in the Northridge earthquake—Los Angeles County, Fillmore, Los Angeles, San Fernando, Santa Monica, Santa Clarita, Simi Valley, and Whittier—were interviewed to assess the status of local safety elements and their effectiveness. To get a similar perspective on the 1989 Loma Prieta earthquake, planners from Santa Cruz County, Los Gatos, Santa Cruz, and Watsonville were also interviewed. These interviews revealed some common themes:

- The officials generally believed their safety elements had been useful, either for their educational value to local planners and decision makers or because they provided leverage to require mitigation of specific seismic hazards.
- The officials believed that the safety elements needed to be improved.
- More recent safety elements contained better seismic information and more effective guidelines for land use decision making than older elements.
- Many local officials were surprised by damage patterns in their communities. Their safety elements had not adequately anticipated the effects of the earthquake because they had only cursory geological and geotechnical information and little or no information on building vulnerability.

Reducing and managing earthquake risk at the local government level can be enhanced by use of the information contained in well-done safety elements in a general plan. The policy direction provided by general plans can give local governments the framework needed to balance competing community concerns with resource limitations. Review of current land use planning practices and consideration of the lessons from the Northridge and other earthquakes indicates that up-to-date plans based on good seismic hazard and vulnerability data are not generally available. General-plan law is not used as effectively as it could be. The following recommendations will make these existing programs more effective.

Recommendations

The Commission recommends that:

- CDMG complete the SHMA program by 2005.

  The basic information that these maps provide is critical to the updating of general plans. Improving zoning and subdivision decisions will lessen future earthquake losses. The State Geologist must establish priorities to target the most populated areas with the greatest risk. All the state's urban areas should be mapped, and revised maps should be issued as better information is available.

- Legislation be enacted requiring review of the safety element of general plans every five years to incorporate new information; the information in maps prepared under the SHMA should be incorporated within one year of the date final maps are provided to local jurisdictions.

  Existing law does not require periodic revisions to incorporate new seismic information, and even though local jurisdictions are required to incorporate the information from maps prepared under the SHMA, there is no deadline. Since new geologic and geotechnical information is constantly being developed, a requirement that the seismic aspects of safety elements be reviewed and updated every five years will make sure that new seismic hazard information is incorporated.

- Legislation be enacted to make the existing optional CDMG review of safety elements mandatory for CDMG.

  The usefulness of safety elements can be improved if the information is up to date and properly described. Existing law

requires local governments to submit a draft copy of revised safety elements to CDMG, but doesn't require CDMG to review them. The staff of CDMG's Environmental Review Project has been reduced from six people to one over the last few years and is no longer able to provide timely and meaningful reviews of these documents. As a result some local plans are not as useful as they should be.

- Legislation be enacted to require that the safety elements of general plans address seismic vulnerability of existing building stock, or inventory, and contain risk-mitigation strategies. Description of the building stock should be included in enough detail to support the risk-mitigation strategy.

  Besides the intensity of shaking, the vulnerability of the building stock is the greatest factor influencing the extent and location of damage and the greatest cause of losses. Very few general plans include inventories of vulnerable buildings and facilities or strategies to reduce the resulting risk. By not anticipating damage patterns, local governments lose the opportunity to manage their risks, plan their emergency response, and prepare for recovery. The general plans and long-term local government policies should provide the basis for community retrofit programs.

- Legislation be enacted to require CDMG to convene a high-level independent review board for the preparation and review of guidelines and maps prepared under the SHMA.

  The usefulness of maps will be improved through peer review by others who have experience in hazard mapping and those who will use the CDMG products.

- CDMG work with local governments to establish a systematic program to ensure that the information provided by the SHMA program can be easily incorporated into general plans and zoning, subdivision, and environmental quality decisions.

  Since the advice and assistance of a geologist or geotechnical engineer is not available to many smaller local jurisdictions, information provided under the SHMA must be in a form that can be readily understood by nontechnical decision makers.

- CDMG work with the Insurance Commissioner and representatives of the insurance industry to ensure that mapped hazard areas are not misinterpreted and used incorrectly in issuing insurance policies.

  A potential hazard in an area may be interpreted as a certainty. Conversely, insurers may not be adequately informed about mitigation measures incorporated in a project.

- CDMG and OES support the preparation of damage scenarios, including localized scenarios and scenarios for areas of the state not presently covered.

  Damage scenarios are both a powerful educational tool for decision makers and a valid way to develop mitigation and emergency plans. Damage scenarios also can be used for recovery planning. New computer programs under development by the National Institute of Building Sciences will allow for the rapid and inexpensive preparation of scenarios using building inventories and geologic maps. The damage patterns of the scenarios should be based on a range of seismic events (not a single type and magnitude of earthquake); they should have subregional foci (instead of a broad regional focus); and they should assess potential damage to residential, commercial, and industrial developments as well as public infrastructure.

Zoning, Subdivision, and Environmental Reviews

The day-to-day implementation of safety elements is done primarily through zoning, subdivision decisions, and environmental review procedures. Usually, these decisions and reviews pay

only cursory attention to earthquake hazards and assume that building plan checking procedures will address them. Unfortunately, routine plan checking and environmental reviews do not consistently address site-specific hazards.

Zoning

In zoning, a city or county divides its territory into various districts and specifies allowable land uses and development standards, such as minimum lot sizes and maximum building heights, for each district. Like a general plan, a zoning ordinance includes both a map showing the distribution of land uses and text setting out development regulations.

Although few zoning districts address seismic concerns exclusively, there are several ways in which seismic concerns are, or can be, reflected in zoning regulations:

- Areas with seismic or geological hazards such as unstable slopes or liquefaction potential can be zoned to allow only low-density uses such as grazing, agriculture, open space, or very-low-density residential use to discourage substantial development.
- "Overlays," or zones that require special review procedures or development standards, can be used to reflect seismic hazards in specific areas of the community.
- Zoning can be used to provide incentives such as density bonuses or parking requirement waivers to encourage seismic risk mitigation of buildings vulnerable to earthquakes.

Subdivision Review

Pursuant to the state Subdivision Map Act, local governments review proposed subdivisions and their related improvements and impose conditions necessary to conform with the local general plans and ordinances. The act generally requires that soils reports be submitted in conjunction with proposed subdivisions, but often these reports do not adequately deal with seismic hazards. The SHMA, by providing maps depicting areas with potential hazards and requiring site-specific analysis of the hazards, should eventually remedy deficiencies in current soils reports.

Environmental Review

Approvals of development projects, as well as adoption of most development plans and regulations, are subject to requirements of the California Environmental Quality Act (CEQA). This means that projects must be reviewed for their potential environmental effects and, depending on the results of the initial studies, may be examined more closely in environmental impact reports (EIRs) and modified as necessary to reduce negative environmental effects.

The CEQA and the state CEQA guidelines devote little attention to seismic hazards and earthquakes. Mere compliance with the building code is often considered adequate mitigation even when the code does not have requirements that address hazards. There is no requirement that the EIR assessment of seismic hazards be prepared or reviewed by a geologist or other qualified professional, so the information used in the review may be inaccurate or incomplete. Moreover, the guidelines do not require that mitigation measures be taken to reduce earthquake risk.

The Northridge Earthquake

None of the jurisdictions interviewed in connection with the Commission's Northridge study reported having adopted zoning provisions aimed exclusively at seismic hazards, though virtually all jurisdictions had adopted hillside ordinances that address seismic and geologic hazards in conjunction with aesthetic and open-space concerns. It appears that existing state zoning statutes are adequate to allow the use of zoning authority to address seismic safety once better information is available from the SHMA program and CEQA guidance is provided.

The areas suffering the most serious damage during the Northridge earthquake were more mature communities that had developed before the passage of CEQA. Thus, in these areas, CEQA has been applied more often to infill projects than to

projects involving major location decisions. The responses of the planners and engineers interviewed from the eight cities and counties affected by the earthquake, which presumably reflect practices statewide, indicate that seismic hazards are routinely considered in their environmental reviews. Although the emphasis on seismic hazards varies, seismic hazards are generally not considered major environmental issues in initial studies or EIRs. Typically, seismic hazards receive much less attention than such issues as traffic or wildlife habitat. Some communities reported that the primary seismic consideration in environmental reviews is whether the project is located within an Alquist-Priolo earthquake fault zone, even though most earthquake damage is caused by shaking and other types of ground failure outside the zones. Mitigation measures will not be effective unless they address these primary hazards.

Recommendations

The Commission recommends that:

- State CEQA guidelines be amended to require that EIRs address seismic hazards, and engineering geologists and civil engineers, practicing within their areas of competence, review the hazards and proposed mitigation measures.

  Interviews conducted by the Commission indicate that there is a general presumption that current laws and regulations—the Alquist-Priolo Earthquake Fault Zoning Act, the Uniform Building Code, and hillside ordinances—adequately address seismic hazards. EIRs seldom recommend special mitigation measures to address seismic risk such as those that would be recommended by geotechnical or soils reports.

- Legislation be enacted to amend the Subdivision Map Act to require that geologic and geotechnical reports addressing seismic hazards be required for all major (five lots or more) subdivisions unless information is already available or until superseded by SHMA maps and that reports be reviewed by local government staffs or consultants with appropriate credentials.

  Soils reports submitted in connection with subdivision proposals too often focus only on the immediate soil conditions and ignore more basic geotechnical concerns, including seismic hazards. Furthermore, there is no requirement that a geologist be involved in preparing or reviewing these reports, so the information presented may not be accurate or usable by the local jurisdiction's decision makers.

Typically, seismic hazards receive less attention than traffic or wildlife habitat.

Alquist-Priolo Earthquake Fault Zoning Act

Prompted by damage caused by surface faulting in the 1971 San Fernando earthquake, the state Legislature passed the Alquist-Priolo Special Studies Zone Act in 1972. In 1993 the act was renamed the Alquist-Priolo Earthquake Fault Zoning Act (the Alquist-Priolo Act). Its purpose is to prevent construction of buildings for human occupancy across active faults that may rupture. (Figure 75 is a portion of an Alquist-Priolo map.)

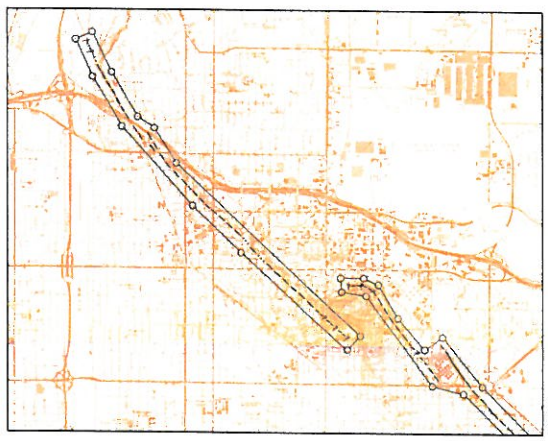

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Figure 75. A portion of an Alquist-Priolo map, showing the special studies zones beside active faults.

The Alquist-Priolo Act requires the State Geologist to delineate earthquake fault zones, generally one quarter of a mile wide, along California's active fault traces. Once the State Geologist officially designates an earthquake fault zone, the affected jurisdictions must make this information public, and real estate agents must disclose to potential buyers that the property is located in a designated fault zone. According to CDMG, 12 earthquakes of magnitude 6.0 or greater in California since the passage of the Alquist-Priolo Act had associated primary or secondary surface displacement, and nine of those earth-

Thrust faults, like the one that caused the Northridge earthquake, often rupture over a broad area with discontinuous and erratic displacement patterns that lead to confusion in interpretation

quakes resulted in surface displacement within earthquake fault zones already delineated by CDMG.

The city or county must also adopt procedures for reviewing and approving permits for new buildings to be located within the zones. The Alquist-Priolo Act applies to new or expanded structures for human occupancy, defined as structures that will be occupied more than 2,000 person-hours per year except single-family wood-frame dwellings and wood-frame dwellings of up to two stories when part of developments of three units or fewer. Before a city or county can approve a project within a designated fault zone, the applicant must, with some exceptions, submit a registered geologist's report describing the possibility of surface rupture. Typically, local governments incorporate the Alquist-Priolo Act information, policies, and criteria into their general plan safety elements and adopt regulations and guidelines for implementing them at the project review level.

The effectiveness of the Alquist-Priolo Act has been strenuously debated. The most frequent criticism of the act is that it designates as active only faults with evidence of recent surface rupture. Other types of evidence along a fault—microseismicity, recognizable geodetic change, or youthful geologic and geomorphic patterns indicating recent tectonic activity—cannot be used for designating a fault as active even if it shows evidence of activity.

Another criticism of the Alquist-Priolo Act is that some types of recent surface rupture are not mapped. Only clearly defined geological surface ruptures are delineated as earthquake fault zones. This is because fault descriptions must be clear since the act prohibits locating structures for human occupancy over fault traces, and setback requirements demand the clear delineation of the fault trace on the ground surface. Complex surface displacement patterns can make it difficult to delineate a useful fault trace; for example, thrust faults often rupture over a broad area with discontinuous and erratic displacement patterns that could lead to confusion in interpretation.

A third problem is that because the act was written to apply to structures for human occupancy subject to local government permit authority, it does not protect lifelines, industrial facilities, or state-owned buildings.

A new definition of "active fault" is needed. Many people mistakenly believe that faults not designated as active under the act will not cause earthquakes and nearby shaking and that they are safe from earthquakes if they live outside designated earthquake fault zones. However, many other faults, even though they lack clearly defined or recent surface ruptures, are capable of causing damaging earthquakes—the Northridge, Whittier Narrows, and Coalinga earthquakes all occurred where there was no Alquist-Priolo Act designation. Mitigation measures might be addressed as part of the SHMA procedures.

At present, the Alquist-Priolo Act does not cover many utilities, public-agency buildings, and small-occupancy buildings and facilities. Extending the act to cover projects of this nature will make it more effective in reducing risk.

The Northridge Earthquake

The Northridge earthquake did not occur on a mapped fault and caused no primary surface faulting within any Alquist-Priolo Act earthquake fault zone, although there was some evidence of secondary surface deformation. However, general information on the earthquake, plus 20 years of experience with the Alquist-Priolo Act, suggests the need for changes to improve the use of existing knowledge.

The Alquist-Priolo Act would be more useful in reducing earthquake damage and speeding recovery if the definition of "earthquake fault zone" were expanded and if it were more broadly applied.

Recommendations

The Commission recommends that:

- Legislation be enacted to allow designation of active fault zones based on all viable geologic, geodetic, and tectonic evidence and provide for alternative mitigation measures

to be defined by the Mining and Geology Board as appropriate to complex areas where the location of potential fault ruptures is uncertain.

- Legislation be enacted to apply the Alquist-Priolo Act to all publicly owned facilities, critical facilities, and lifelines, including public utility pipelines and facilities in which hazardous materials are used or stored, and to provide for alternative mitigation measures appropriate to lifelines.

Inundation Mapping

California has over 1,300 dams that impound substantial volumes of water. The failure of any of the 800 largest of these dams could cause deaths and injuries, displace people, spread hazardous materials over a wide area, and do extensive damage to property, electrical generation facilities, transmission lines, and water supplies. A failure damaging lifelines could affect life-support systems in communities far outside flooded areas.

Following the near-collapse of the Van Norman Dam in the 1971 San Fernando earthquake, the Emergency Services Act was amended to require the owner of any dam whose failure could result in death or injury to prepare and submit to OES an inundation map showing areas of potential flooding. The act also requires cities and counties to adopt emergency procedures for the evacuation and security of people within these potential inundation areas.

The owners of some dams now subject to the mapping requirement were not originally required to prepare inundation maps because in 1972, when the law was passed, there was no downstream population at risk. Present law does not specify at what point an inundation map must be prepared as downstream areas begin to develop.

The 1972 legislation gave dam owners six months from the effective date of the law to complete the required inundation maps but, as of May 1994—over 20 years after the deadline had passed—OES reports that the owners of 200 to 300 dams have yet to comply.

There is no requirement that inundation maps be updated or revised to reflect changes in downstream drainage channels or erection of barriers such as freeways that could dramatically change the flow patterns of floodwaters. This means that both evacuation planning and land use planning leading to development decisions may be based on outdated or erroneous hazard scenarios.

Since the statute calling for mapping inundation areas is in the Emergency Services Act and is intended to guide evacuation planning, inundation maps now play almost no role in land use planning and decision making.

At present there is little incentive for state and local agencies to consider the inundation threat in approving new development. CDMG is authorized, but not required, to include inundation areas on maps prepared under the SHMA, and safety elements of local general plans must consider seismically induced dam failures along with other hazards. Although inundation resulting from dam failures would logically be a subject of consideration in environmental reviews under CEQA, it is not mentioned in the state CEQA guidelines.

Some federal agencies have already completed inundation maps for their dams, but not all. Emergency response and land use plans need complete information on areas of potential inundation.

Although the failure of levees was not an issue in the Northridge earthquake, it is apparent that many levees, especially in the Sacramento-San Joaquin River Delta, are critical to the safety of existing water supplies and development. Inundation maps are not required for these areas even though many levees are vulnerable to failure from earthquake shaking.
Inundation maps depicting areas at risk from flooding caused by the failure of levees would be used to guide emergency evacuation, land use planning, water supply restoration, and development decisions.

The Northridge Earthquake

Following the Northridge earthquake, the Division of Safety of Dams, part of the Department of Water Resources, inspected 108 dams within a 47-mile radius of the earthquake's epicenter and found 13 with some cracking or movement; none was judged to be a safety hazard.

The Pacoima Dam, located in the San Gabriel Mountains about 11 miles from the epicenter, was the most significantly damaged. It experienced peak ground accelerations in excess of 0.7g. The water level was 131 feet below the crest at the time of the earthquake. Though the Pacoima Dam is rarely near capacity (3,700 acre-feet) and the probability of the simultaneous occurrence of peak capacity and a damaging earthquake is remote, the potential flood could affect over 280,000 people downstream.

As of May 1994—over 20 years after the deadline—OES reports that the owners of 200 to 300 dams have yet to complete required inundation maps.

Recommendations

The Commission recommends that:

- Legislation be enacted to impose sanctions on dam owners who fail to prepare and submit inundation maps by December 31, 1996.
- Legislation be enacted to require that inundation maps be reviewed and revised whenever downstream development could significantly change hydrologic patterns and to require that inundation maps be reviewed every ten years and revised when necessary to reflect new data and to incorporate new inundation mapping technology.
- Legislation be enacted to amend land use laws to require state and local agencies to make specific findings regarding the acceptability of inundation hazards before approving development of critical facilities (for example, hospitals, schools, emergency response facilities, hazardous material storage, and sewer treatment plants) within potential inundation areas.
- The Governor petition federal agencies responsible for dams in California to provide inundation maps for their facilities to the state and local agencies.
- Legislation be enacted to require owners to prepare inundation maps for low-lying areas protected from flooding by levees.

Hazardous Materials

Building industry regulations, such as the Uniform Building Code, the Uniform Plumbing Code, and the Uniform Fire Code, which are adopted and enforced by cities and counties, address structural issues relating to the use and storage of hazardous materials. The use, storage, and handling of hazardous materials are also subject to city or county zoning regulations; therefore, the scope and stringency of regulations varies from community to community. Where discretionary approvals are required (for example, general-plan amendment, rezoning, and use permits), projects are also subject to environmental review under CEQA.

Businesses that handle hazardous materials, even in fairly small amounts, must submit annual inventories of the materials they use and must prepare a business plan that includes plans for responding to a release or threatened release of hazardous materials. Local agencies must also prepare their emergency response plans concerning hazardous materials on the basis of this information. Businesses that handle acutely hazardous materials must prepare risk management and prevention programs that comprehensively evaluate risks and identify engineering controls and prevention measures.

The Northridge Earthquake

There were over 100 reported incidents involving hazardous materials related to the Northridge earthquake—pipeline breaks, tank failures, falling containers, and transportation accidents. Although these incidents were manageable, it is evident that life-threatening incidents from releases of hazardous materials caused by earthquakes are likely and can be expected to be much more extensive than those experienced in the Northridge earthquake and other recent moderate events.

Among the most significant incidents were:

- Three separate fires, suspected to have been ignited by gas leaks or chemical reactions, totally or partially destroyed nine science laboratories at the California State University, Northridge.
- The earthquake derailed a Southern Pacific Railroad train. One of the six derailed cars containing sulfuric acid leaked approximately 8,000 gallons. Approximately 400 gallons of diesel fuel leaked from the overturned locomotive. Two cars containing ethylene glycol and petroleum were also derailed but did not leak.
- A high-pressure natural-gas line on Balboa Boulevard in Granada Hills ruptured, leading to a fire that burned overhead utility lines and five nearby homes. There were similar natural-gas fires in streets in Fillmore and Santa Monica.
- Several pipelines that carry petroleum products from production fields to Los Angeles Harbor were damaged and leaked.
- The Four Corners Pipeline No. 1 leaked at a failed weld in Santa Clarita, releasing over 4,000 barrels of crude oil, temporarily blocking access to a hospital before flowing into the Santa Clara River.

The Northridge earthquake demonstrated how little we know about the hazardous materials used, produced, transported through, and stored in our communities and the risks they pose during earthquakes. Improving the knowledge base and decision making regarding hazardous materials will require the cooperation of the State Fire Marshal, the California Highway Patrol, and the Public Utilities Commission. The information in safety elements should be used when decisions are made regarding acutely hazardous materials.

The threat of larger earthquakes and large numbers of hazardous-materials incidents makes it necessary to establish policies to guide future development and redevelopment to reduce the combined hazard. Land use planning laws should be amended to require the consideration of seismic hazards and building vulnerability in cases in which significant quantities of acutely hazardous materials are stored.

Recommendations

The Commission recommends that:

- State general plan guidelines be revised to require safety elements to include maps that depict where acutely hazardous materials are stored, used, and transported and their relationship to seismic hazards and that circulation elements address the existing and proposed location of pipelines transporting hazardous materials.
- Legislation be enacted to amend the Alquist-Priolo Act and the SHMA so they apply to all facilities that produce or store reportable quantities of acutely hazardous materials.

Life-threatening incidents from hazardous-material releases caused by earthquakes are likely.

Historic Buildings

Historic buildings are a valuable community and cultural resource. These buildings create the identity of many communities. Besides the aesthetic contribution, these buildings often provide affordable housing and economically attractive retail and commercial space. Land use planning provides the policy framework to protect community resources and to address their seismic vulnerability.

The Northridge earthquake is only the most recent in a string of California earthquakes that have severely damaged and destroyed historic structures. Although historic buildings are no more vulnerable than other buildings of similar vintage and design, the Coalinga, Whittier Narrows, Loma Prieta, and Cape Mendocino earthquakes all damaged older downtowns, which are still scarred and struggling to recover. Historic buildings constructed of unreinforced masonry (URM) are most susceptible to earthquake damage, although wood-frame, concrete, and steel-frame historic buildings have also been severely damaged.

The seismic retrofit of older buildings has proven effective in increasing the survival of historic buildings during earthquakes, but many owners

of private buildings simply cannot afford the cost, which is often not justified by the building's revenue potential. Moreover, retrofit usually will not guarantee that a building will not be extensively damaged in an earthquake, so owners must also consider the possibility of high post-earthquake repair costs or the total loss of the building. Federal tax credits are available for rehabilitating historic buildings; however, few financial incentives for seismic retrofit reflect the value these buildings have to communities. The State Historic Building Code needs to be revised to reflect statutes that make its use mandatory and to provide explicit guidelines for the seismic safety of historic buildings.

When an earthquake strikes, some owners of older and historic buildings find it more economical to have their buildings demolished at public expense than to pay for repairs. Under some circumstances, FEMA will reimburse local governments for demolishing damaged privately owned buildings but will not, as a general rule, pay for repairs. A few private owners may qualify to borrow from the Small Business Administration, but for most, economics favor demolition over repair. As a consequence, vulnerable historic buildings are lost after nearly every earthquake.

The Northridge Earthquake

Although the Northridge earthquake's epicenter was in the San Fernando Valley, an area of fairly new development, the earthquake damaged many historic buildings, especially in Santa Monica, Fillmore, and east Hollywood. The Los Angeles Conservancy estimates that well over 1,000 buildings, out of the 112,000 buildings evaluated for damage, were historic. (Figure 76 shows damage to a historic building.)

The Brown Derby in Hollywood, the Masonic Temple in Fillmore, and the First Christian Church in Santa Monica are notable historic structures demolished following the earthquake. As of May 1994, FEMA had approved demolition of 25 historic buildings and was reviewing proposed demolition for another 25 to 30. Without doubt, other historic buildings not documented as part of the FEMA process were also damaged or demolished.

Several major problems make the challenge of safeguarding historic buildings from earthquakes difficult:

- The State Historic Building Code does not have standards that adequately address life safety or seismic damage to structures.
- Existing financial incentives are insufficient to encourage seismic retrofit of historic buildings.
- The expertise and technical guidance for dealing with historic buildings after an earthquake is often too late to help those who need it.
- For economic reasons, many historic buildings are retrofitted to levels that will improve life safety during earthquakes but will not prevent the loss of the building.

Recommendations

The Commission recommends that:

- The State Historical Building Safety Board revise the State Historic Building Code to include minimum life safety standards and guidance on measures to control damage.

  Seismic retrofitting of historic buildings can lessen building damage and possibly avert the need for demolition, thus protecting historic heritage as well as saving lives.

- The California Office of Planning and Research, in consultation with the Office of Historic Preservation, publish guidelines for adding optional historical resources elements to local general plans to address the seismic retrofit of historic buildings.

  Many communities have buildings or areas with economic as well as historical importance. Land use plans provide a policy framework for local government to adopt and implement policies to protect valuable historical assets and improve seismic safety. Guidance can help in the development of plans to safeguard these buildings from earthquakes.

Redevelopment

There are 375 redevelopment agencies in California administering approximately 665 redevelopment project areas. Many of these areas encompass older downtowns, which are particularly susceptible to earthquake damage because most of their buildings were built before the mid-1970s, when modern building codes became effective. They often include concentrations of historic buildings that lend character and charm to communities.

Redevelopment law grants broad powers to redevelopment agencies, making them capable of addressing earthquake-related problems. The most frequently used tool for mitigating seismic hazards is tax-increment funding to subsidize seismic retrofits or upgrades of buildings, bridges, and public facilities to withstand the effects of earthquakes. Redevelopment funding has been particularly helpful in upgrading unreinforced masonry buildings.

Redevelopment powers can be used for a wide variety of purposes during post-earthquake recovery, including financing repairs of damaged structures, alleviating hazardous conditions (including demolition of hazardous structures), and providing relocation and temporary housing assistance to property owners and residents. Recognizing how development powers can help in responding to disasters, the state Legislature enacted the Community Redevelopment Financial Assistance and Disaster Project Law (the "Disaster Law") in 1964. The Disaster Law allows a city or county that does not have a redevelopment agency to use simplified and expedited procedures to create one and to adopt a redevelopment plan for a disaster area. It also allows existing agencies to create, amend, or merge projects according to the same procedures. Normal procedural requirements waived by the Disaster Law include detailed documentation to support the adoption of a plan, environmental review under CEQA, community participation, and consultation with other taxing entities before adopting a plan.


Tobin

Figure 76. The historic First Christian Church in Santa Monica was seriously damaged in the earthquake.

The Northridge Earthquake

Four of the eight affected communities interviewed had already used redevelopment powers to address problems resulting from the Northridge earthquake, and three of the eight had either taken or intended to take advantage of the Disaster Law.

An issue raised during interviews with communities affected by the Northridge earthquake was the spending caps required of all redevelopment projects. Agencies were concerned that adding disaster recovery needs to the expenditures for projects already planned could cause them to exceed their spending limits.

Unless redevelopment plans explicitly include earthquake-related project descriptions (for example, seismic retrofits), agencies that have established relatively low spending caps may be reluctant to spend their scarce resources on such efforts.

Recommendations

The Commission recommends that:

- Legislation be enacted to allow redevelopment agencies to increase spending caps easily after a natural disaster to accommodate disaster-recovery activities, including repairs to meet appropriate standards.

- Legislation be enacted to add to the definition of "blight," when designating a redevelopment project area, those structures deemed by the local jurisdiction to pose an unacceptable risk of collapse in earthquakes.

  Strengthening these vulnerable structures will improve the area's ability to recover, physically and economically, from earthquakes. Including seismically vulnerable buildings in the definition of blight will make redevelopment powers a more effective tool.

Planning for Recovery

In the aftermath of an earthquake, there is intense pressure to rebuild the damaged parts of the community as they were before the earthquake and to do it as rapidly as possible. Human nature favors a return to the way things were. Businesses want to restore operations, and residents are understandably eager to repair or rebuild their homes so they can return. At the same time it is important to remember that earthquake damage and the rebuilding process provide the opportunity to mitigate future disaster damage as well as to realize other community objectives and change land use patterns and regulations.

Because of the strong desire to return to normal after earthquakes, the owners of damaged properties tend to repair or reconstruct their buildings to their pre-earthquake condition; often they have neither the interest nor the ability to pay for seismic upgrades that would avoid repeating losses in future earthquakes. A common attitude is that they have already had their earthquake. This tendency is reinforced by state and federal post-earthquake disaster aid policies that do not clearly require upgrades and by a lack of repair standards.

The Northridge Earthquake

The general plans of eight jurisdictions affected by the earthquake were reviewed. Only two of them had safety elements that addressed post-earthquake recovery and reconstruction.

Recommendations

The Commission recommends that:

- The CBSC amend the CBC to include triggers to require that alterations, repair, retrofit, and reconstruction activities incorporate seismic upgrades to mitigate future earthquake damage. The code should allow setting aside mandated upgrades not related to life safety that may be triggered when elective remodeling projects are undertaken.

  At present neither government programs—loans, tax incentives, and grants for earthquake repairs—nor payments made under private insurance policies require seismic retrofits unless there are trigger mechanisms in the building code. The triggers should have some flexibility in interpretation, and standards for repairs and retrofits should include cost-effective measures.

- Legislation be enacted to require local general plans and emergency plans to address post-earthquake recovery and rebuilding.

  Until fairly recently, planning for post-earthquake recovery and rebuilding had received little attention, principally because the state's guidelines for emergency response planning do not require it to be a part of local emergency plans.

Training

Knowledgeable local government decision makers and professional staff are key to the proper integration of earthquake risk-mitigation measures into land use planning. Representatives of the eight jurisdictions interviewed after the Northridge earthquake stressed the educational value of preparing safety elements and the knowledge gaps that occur when those involved move on to other endeavors.

The Northridge Earthquake

Interviews with land use planners in jurisdictions affected by the Northridge, Loma Prieta, and Whittier Narrows earthquakes point to the critical need for those professionals involved in plan-

ning to be properly trained in seismic principles and to keep up to date. For example, safety elements are often prepared by staff specialists or consultants, and staff planners who must carry out the policies are not deeply involved.

Those who become knowledgeable during the writing and adoption of safety elements may move on to other positions and jurisdictions, and their replacements may have only a cursory knowledge of their contents. Knowing the issues, understanding seismic hazards and building vulnerability, and being aware of potential mitigating actions are essential to taking advantage of risk-reduction opportunities and properly balancing seismic safety with other community concerns.

Recommendation

The Commission recommends that:

- The American Planning Association, the League of California Cities, and the County Supervisors Association of California institute formal training on earthquake principles for their members.

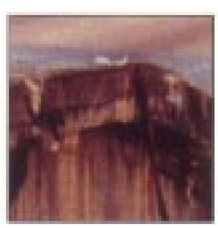
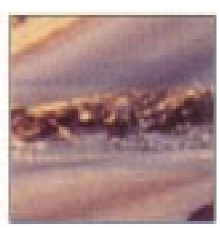
CHAPTER VI

Reducing Earthquake Risk in California

The 167 recommendations presented in the previous five chapters of this report cannot make California safer from earthquakes unless state and local governments, businesses, and individuals start to pay more attention to reducing earthquake risks. This report provides a prescription for giving seismic safety a level of priority consistent with the enormity of California's earthquake threat.

The Seismic Safety Commission aims to clarify the responsibility and ensure the accountability of those expected to address seismic safety issues, especially those who must carry out the recommendations in this report. The Commission believes that the strategy of integrating seismic safety with other public- and private-sector programs is appropriate, but it recommends taking the additional steps needed to get meaningful results. Seismic efforts must overcome benign neglect, denial, procrastination, and ignorance. The Commission's response to these concerns is woven into many of the recommendations.

Los Angeles Times

The Santa Monica Freeway was one of several major roadways disabled.

Funding is essential to apply the lessons learned from Northridge. Many of the recommendations are not expensive to implement, but significant funding in both the public and private sectors is needed to provide incentives to reduce risk in existing structures and support focused research. The more costly recommendations must not be avoided because of current fiscal problems; instead, modest and affordable commitments should be made now, with a long-term obligation to complete the tasks as funding becomes available. The Commission urges the state to aim for continuous progress even if it is funded with only a modest annual budget.

Seismic efforts must overcome benign neglect, denial, procrastination, and ignorance.

This report's recommendations, listed at the end of the "Executive Summary" and summarized at the end of each section of this chapter, combine to support four fundamental seismic safety goals:

- Make seismic safety a priority
- Improve the quality of construction
- Reduce the risk from seismically vulnerable structures
- Improve the performance of lifelines

To achieve these goals, it is necessary to:

- Define acceptable earthquake risk
- Provide incentives for risk reduction
- Improve the use of earth science knowledge to reduce risk
- Improve the use of land use planning to reduce risk
- Improve the building code development process
- Support focused research
- Improve state seismic programs

The recommendations largely build on existing laws, state and local government efforts, and activities in the private sector. All recommendations are listed under one of two headings: "Immediate Action" (actions the Governor can initiate) or "Legislation" (actions that require new or changed laws). Few of the recommendations suggest dramatic short-term change. Instead, the Commission recommends doing what we already do, but doing it better and more efficiently than in the past. Though amendments to existing statutes are needed, the legal tools generally are in place to reduce and manage seismic risk effectively. Providing policy direction and information, increasing priority, assigning responsibility, and demanding accountability are inexpensive but powerful ways to improve seismic safety efforts.

Making Seismic Safety a Priority

Many of the shortcomings in existing seismic safety programs in both the public and private sectors are caused by a lack of understanding of and support for seismic concerns. Seismic safety is seldom the primary interest of any business, individual, or agency. Responsibility for decisions involving earthquake risk is often vague; agencies lack clear authority and adequate resources; and accountability is not clearly established. Even if the public and private sectors endorse new programs and increase spending, carrying out these efforts must be afforded the priority to ensure consistently high-quality work.

The Commission recognizes that seismic safety must be balanced with other concerns to be successful over the long term, but planning and building decisions too often ignore seismic safety or incorrectly assume that it has already been addressed in some other way. Although state and local governments have a responsibility to protect public health and safety, earthquake risk-reduction efforts typically do not receive the attention necessary in light of California's earthquake risk. Seismic safety is emphasized after earthquakes strike but is gradually pushed aside by other concerns. Seismic efforts push uphill against a prevailing perspective that they can be delayed—or may not be necessary. Earthquake programs are often regarded as too expensive or only marginally relevant to an agency's program or a business' line of work. Seismic safety is treated too casually and inconsistently for the public safety or the economic issues at stake.

Ensuring that seismic risk receives proper consideration in planning and building deci-

sions involves making pertinent information available to responsible decision makers and ensuring the competence of the licensed professionals involved. Responsibility and authority must be clear, resources must be provided, and accountability must be demanded from organizations and agencies whose missions affect seismic safety if California is to reduce seismic risk in the manner expected by its citizens.

The place to start raising the priority of seismic programs is with state agencies and state-supported programs, which either affect state government interests directly or provide leadership, information, and standards to local governments and the private sector. The Commission recommends that the Governor, by executive order, direct each agency secretary to initiate efforts to raise the priority of the seismic safety efforts carried out within his or her agency. As high-level administration officials, the secretaries are ideally situated to review state agencies' progress in carrying out existing seismic programs and ensure that each agency provide appropriate priority to seismic concerns.

Immediate Action

The Commission recommends that:

- The Governor direct agency secretaries to be responsible for the progress of every department, board, and commission under their jurisdiction in carrying out their seismic safety responsibilities.

Improving the Quality of Construction

The need to improve the quality of construction is one of the most important lessons from the Northridge earthquake. The recommended actions will improve the quality of design and engineering, design review, and construction inspection. The earthquake performance of public school buildings, which are built using a code similar to that used for normal buildings but with higher quality control standards, showed that markedly better earthquake performance can be achieved at minimal additional cost.

Immediate Action

The Commission recommends that:

- The Governor direct that California's codes and regulations be amended to:
  - Require that a single design professional be responsible for the complete seismic design of each engineered building, indicate earthquake bracing elements and connections on plans, specify quality assurance plans, and observe construction of critical elements.
  - Improve the way licensing boards test engineers, architects, and geologists on seismic principles and aggressively enforce licensing board rules regarding professional competence in seismic safety matters.
  - Require plan checkers to review the lateral force resisting elements and inspectors to inspect these elements thoroughly, require independent peer review of important or complex buildings and authorize state and local government building departments to reject incomplete or incompetent plans, collect additional fees when the poor quality of design creates additional review work, and file complaints with licensing boards.

Seismic safety is treated too casually and inconsistently for the public safety or the economic issues at stake.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend the practice acts for professional engineers and architects to require continuing education and the title act for structural engineers to define the level of seismic expertise necessary to attain and keep the license and to require structural plan checking of engineered buildings by licensed professional engineers or architects.
  - Require testing of contractor license candidates on basic seismic safety principles in construction and continuing education of licensees.

- Require building inspectors and plan checkers to be trained and certified under programs provided by recognized organizations.

Reducing the Risk from Seismically Vulnerable Structures

Local governments must take the lead, but the state and federal governments must provide information and incentives.

In California the greatest seismic risk comes from existing buildings. Although only a small percentage of them are vulnerable to life-threatening failures or collapse in earthquakes, identifying specific buildings, deciding on the level of retrofit necessary, and setting priorities remains a difficult engineering, economic, and political challenge. Local governments, which are responsible for privately owned buildings, must take the lead, but the state and federal governments must provide design and building code information and financial incentives if significant progress is to be realized. Executive action and legislation are needed to improve the manner in which the state deals with state-owned buildings and to reduce the risks from the most hazardous of privately owned buildings.

Immediate Action

The Commission recommends that:

- The Governor require state agencies to carry out the recommendations in the report *Policy on Acceptable Levels of Earthquake Risk in State Buildings* (Seismic Safety Commission report SSC 91-01).
- The Governor require the University of California (UC) and the California State University (CSU) systems to prepare capital budget plans for seismic retrofitting of all university buildings that pose unacceptably high risks to life by the year 2005, to determine whether they have the ability to restore critical educational and research programs following damaging earthquakes, and to begin addressing this concern in retrofit programs.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend planning laws to require general plan safety elements to include a generalized description of seismically vulnerable building types by neighborhood and a plan to mitigate the risk from these buildings.
  - Enact legislation to require state and local building code enforcement agencies to identify potentially hazardous buildings and to adopt mandatory mitigation programs by the year 2000 that will significantly reduce hazardous and unsafe buildings by the target year of 2020.
  - Require public-school and community college districts to evaluate the seismic vulnerability of school structures built before 1976 and retrofit structures with significant life safety risks and to evaluate and abate life-threatening nonstructural hazards.
  - Require a portion of future school bond proceeds be used to abate life-threatening structural, nonstructural, and building contents seismic deficiencies.
  - Require that private-school buildings, including preschool buildings housing more than 25 students, be evaluated for structural, nonstructural, and building contents seismic hazards upon sale or lease renewal, and that life-threatening risks be mitigated.
  - Require the UC and CSU systems to adopt guidelines that require seismic retrofit as a condition of carrying out major renovations, reoccupancies, additions, and repairs.
  - Place a general obligation bond measure on the 1996 ballot to fund the retrofit of seismically vulnerable state-owned buildings and local government essential services buildings.

Improving the Performance of Lifelines

Lifeline networks provide critical services to California's communities. These systems are vulnerable to earthquake-caused interruptions because they are made up of hundreds or thousands of components and cover wide areas. Although localized short-term lifeline outages should be anticipated after earthquakes, there are a number of actions that can reduce lifelines' vulnerability to earthquakes, improve their reliability, and provide reliable backup services to those who must remain in action after earthquakes.

Immediate Action

The Commission recommends that:

- The Governor direct Caltrans to revise its retrofit priorities to give more weight to the importance of structures, accelerate the toll bridge retrofit program, meet its stated project completion goals for retrofitting vulnerable structures, undertake a study of the effects of near-source ground motion on seismically isolated bridges, and continue support for research and instrumentation of bridges.
- The Governor direct the Public Utilities Commission (PUC) to take an active role in the seismic safety efforts of the utilities within its regulatory responsibilities. Specifically, the PUC should review the earthquake response and risk-reduction efforts of California's railroads and electric and gas utilities, adopt needed regulations, and draft legislation that will require an earthquake-activated natural-gas shut-off valve at each mobile home park.
- The Governor direct the Department of Water Resources to help water districts identify and address seismic vulnerabilities by disseminating a summary of the causes of earthquake failures in piping systems, tanks, and other system components, as well as a model risk-mitigation program.
- The Governor direct the Division of the Safety of Dams to review its current assessment procedures in light of data obtained from the Northridge earthquake and to conduct seismic reevaluations and increase inspection frequency of high-risk dams in zones of high seismic hazard.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to:
  - Require owners of essential communications and other essential facilities and hospitals to provide reliable backup power.
  - Require water utilities to adopt and carry out long-term seismic risk-mitigation efforts.
  - Require dam owners to place earthquake motion recording instruments on major dams.

Defining Acceptable Risk

Though the poor performance of many structures was obvious in the Northridge earthquake, there is no explicit policy regarding what constitutes minimally acceptable levels of earthquake damage, or risk, in California. This lack of policy direction makes it difficult, if not impossible, for the Commission to recommend what should be done to achieve higher levels of seismic safety, what building designers and code writers should set as performance objectives, or how much should be spent to reduce risk. The effort to define acceptable risk and performance objectives should involve affected organizations.

The objectives of current codes for most buildings and lifelines are generally those established decades ago by the volunteers who drafted the seismic provisions of the building code. At that time it was assumed that government's role was limited to protecting life safety; damage, regardless of how costly or disruptive to the community or state, was the owner's problem. The State of California has never explicitly established modern performance objectives to describe what

levels of earthquake damage are acceptable for buildings that provide residential, commercial, industrial, and institutional space in our state. Moreover, the "building industry"—building code writers, building designers, contractors, manufacturers of building components, and building inspectors—is not set up to encourage buildings that perform better than those "built to code."

From the government's perspective, a key consideration affecting the acceptability of risk is the economic impact of damage. City and state governments are affected by the cumulative impact of individual decisions regarding earthquake risks in buildings over a long period of time. Because major urban earthquakes pose a significant threat to California's economy, an economic framework is needed to evaluate the possible impacts and risk-reduction strategies related to earthquake risk policies.

There is no explicit policy regarding what constitutes a minimally acceptable level of risk in California.

Immediate Action

The Commission recommends that:

- The Governor direct the Department of Finance and the California Office of Planning and Research and request the Joint Budget Committee to convene a panel of economists and other experts to estimate the economic impacts of likely earthquake events.
- The Governor support and participate in a special high-level task force meeting, the "California Earthquake Risk Colloquium," a meeting convened by the Commission to recommend acceptable levels of risk and performance objectives consistent with those levels.

  The "Colloquium" could consist of the Governor and his representatives and representatives of the Legislature, the Insurance Commissioner, the Superintendent of Public Instruction, local government, and organizations representing building owners and managers, contractors, emergency managers, health and human services, banking, insurance, lifeline operations, and seismic experts. It would consider the information developed on economic impacts along with other information on earthquake hazards, building vulnerability, construction costs, and other concerns to arrive at a policy on acceptable risk and performance objectives for residential, commercial, industrial and institutional buildings and lifelines. The "Colloquium" should make its recommendations to the Governor, and they should be incorporated into legislation and adopted before the end of 1996.
- The Governor direct the California Building Standards Commission (CBSC) to work with representatives of the engineering professions, building code groups, building inspectors, and the building industry to implement the performance objectives once they are defined.

  The CBSC should make its recommendations to the Governor, the Legislature, and the International Conference of Building Officials. These recommendations should serve as the basis for revisions to the code's design guidelines and practices in California.

Providing Incentives for Risk Reduction

Incentives are essential tools to encourage earthquake risk reduction. Most economic decisions are made on a short-term basis, considering only current fiscal realities. Mitigation actions pay dividends in the future, when lower levels of damage may make it easier for owners and tenants to resume business and avoid some costly and time-consuming repairs. It is easy to criticize these decisions as penny-wise and pound-foolish, but it is true that an investment in seismic safety may not result in increased value or revenue. If owners cannot afford retrofitting or find a lender, they have no choice but to live with the risk. Incentives can help shift this balance, making it possible and even attractive to invest in seismic safety.

Incentives should be offered by both the public and private sectors. The private sector can be the most powerful influence when it recognizes the

value of reducing seismic risk: potentially hazardous buildings are not as valuable as earthquake-resistant buildings.

Possible incentives include the following measures:

- *Reliable information.* The state and federal government can provide better information to support local government and private-sector efforts to reduce and manage seismic risk. At present, useful information is not readily available to help owners judge the seismic performance of buildings or to make decisions regarding risk, priorities, liability, and cost of retrofitting. The Commission's recommendations call for a number of state agencies to improve the nature and quality of such information.
- *Grants to local government.* The state has a strong interest in reducing damage to publicly owned essential services buildings and other important structures. Not only does earthquake damage to these facilities reduce public safety, but a share of the cost of repair falls on the state. State grants, including matching grants, can stimulate risk-reduction investments; for example, Proposition 122, passed by the voters in 1990, provided for state grants to local governments to pay 75 percent of the cost of seismic retrofit of essential services buildings. Conditions on grants for other purposes can also be used to require compliance with minimum seismic standards. The state, like private investors, should be concerned about risks affecting its potential liabilities.
- *Loans.* State and local government loans for retrofit projects could provide property owners with the capital needed to retrofit when private-sector loans are not available. This type of incentive would be appropriate for owners of single-family homes, manufactured homes, and small businesses. Since many of these borrowers would not qualify for private-sector loans, the rates and payback schedules should be established according to the borrowers' ability to pay, with the loan, interest, and associated expenses held as a lien against the property equity to be paid upon sale or transfer of title, similar to the current elderly property tax program run by the State Controller, if payments do not cover actual costs.
- *Income tax incentives.* Federal and state tax laws can affect retrofit decisions. Seismically vulnerable buildings often provide large amounts of the housing stock for persons with low incomes and for small and start-up businesses. Generally they are older urban buildings, where seismic risk is but one of a number of planning and social concerns. Tax policies that encourage these building could hasten their renewal and, in the case of historic buildings, their preservation.

  Income tax credits or deductions could be given for investments in earthquake safety, and accelerated depreciation schedules would be powerful incentives to encourage investments in seismic retrofit. The loss of tax revenue as a result of these incentives would be offset by lower costs for recovery from future earthquakes.

  Laws affecting passive income, capital gains and enterprise zones should be reviewed and amended to encourage seismic retrofit or replacement of potentially hazardous buildings.
- *Land use planning incentives.* Local governments can provide incentives to retrofit by waiving land use requirements such as dedication requirements, density and parking restrictions, and code requirements that do not affect life safety. They can also issue bonds to fund loans for retrofit projects or provide density bonuses or additional development rights.
- *Insurance, lending, and real estate incentives.* Insurers share seismic risk with owners and tenants. The more susceptible a structure is to seismic damage and the more hazardous its location, the greater the chances that earthquake damage will occur. Although

Potentially hazardous buildings are not as valuable as earthquake-resistant buildings.

earthquake insurance is the most obvious type of policy affected, fire, liability, workers' compensation, business interruption, automobile, medical, and life insurance policies also cover losses caused by earthquakes. Insurers can use premium rate reductions and deductibles to encourage mitigation actions to reduce the risks for each of these lines of coverage.

Lenders also share seismic risk. After the Northridge earthquake some borrowers defaulted on mortgages when damage exceeded their ability to pay for repairs and resume use of the property. Lenders can encourage risk mitigation by requiring a seismic evaluation as a loan condition and adjusting interest rates and payback schedules to reflect their risk of foreclosure on the property should it be damaged by an earthquake.

Real estate agents can help their clients make informed decisions regarding the seismic risk associated with sales and leasing transactions and advise them on how to get reliable information for decision making. Prices should reflect the seismic vulnerability of the property.

- *Liability.* Numerous hazardous buildings throughout the state threaten the life and property of those who live and work in them. Even when the owners know of the risk, they may not inform the tenants and others of the potential for losses. Regardless of whether the owners know, under the law they are responsible for the structure. Clarifying state law regarding owners' liability and obligation to warn tenants would encourage risk-reduction efforts and allow owners and others to manage their earthquake risk more effectively.

Providing meaningful incentives requires investments with an uncertain return; they may not pay off for a long time. The loss of income, new expenditures, and commitment of key personnel to earthquake risk reduction may reduce support for other programmatic or business areas. Developing and offering incentives that are both effective and feasible will require a concerted technical and constituency-building effort.

No single government agency, local government, or business has both the responsibility and expertise to create a broad-based incentive program. Only state government is in a position to do so. Because of the state's responsibility for public safety and its strong self-interest in reducing future earthquake losses, it has the most to gain by exerting the leadership needed to create meaningful incentives for effective seismic risk management.

Immediate Action

The Commission recommends that:

- The Governor convene an ad hoc task force of the agencies and people who can provide incentives to encourage earthquake risk-reduction efforts.

  The key individuals would be administration officials and members of the Legislature responsible for housing, finance, insurance, banking, earthquake recovery, the Insurance Commissioner, and the Superintendent of Public Instruction. The task force should describe possible state-level incentives, arguments for and against, and the mechanism to create those believed to be feasible and effective. This task force should make its recommendations by the end of 1995.

Legislation

The Commission recommends that:

- The Governor support legislation to carry out the recommendations for incentives developed by the "Colloquium" during the 1996 session of the Legislature.

Improving the Use of Earth Science Knowledge to Reduce Risk

Using geological and geotechnical information results in improved decisions that balance earthquake risk with other concerns. However, most construction projects and land use planning decisions do not use the most up-to-date informa-

tion because, even when it is available, potential users do not know of it or do not know how to use it. In part, this is because programs that translate research concepts to products for use by engineers and planners are not well funded. Earth science information must be made available and engineers and architects must use it to lower losses from future earthquakes. The Commission's recommendations are intended to provide critical information in useful formats and make it readily available for land use planning and structural design.

Immediate Action

The Commission recommends that:

- The Governor direct the California Division of Mines and Geology to map areas where active buried faults exist, describe the level of hazard associated with these faults and other subtle faults, complete the Seismic Hazards Mapping Act (SHMA) by the year 2005, and use independent peer review to ensure consistency in all aspects of the SHMA program.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to:
  - Require that state and local jurisdictions enforce as a minimum the Uniform Building Code grading provisions, that fills be designed by qualified professionals considering seismic forces, and that fills be inspected by qualified professionals.
  - Require continuing education for geologists, geophysicists, engineering geologists, and geotechnical engineers as part of the professional license renewal process.

Improving the Use of Land Use Planning to Reduce Risk

General plans, zoning, subdivision regulation, and environmental review are tools that can help local governments manage seismic risk. These planning tools allow a long-term, balanced commitment to seismic safety using existing regulatory and planning programs to achieve community goals. However, the information on natural hazards (areas of potential ground failure and areas where amplified shaking is expected) and human-made hazards (potentially hazardous buildings and hazardous materials) contained in the safety element must be reasonably complete and up to date. Local government planning and investments in infrastructure should consider the potential effects of earthquakes on the financial security of the community, its commerce and housing, and the preservation of historic buildings and the aesthetic character of the community. Although reducing risk through land use planning will take years, the changes necessary to strengthen this effort can be implemented quickly.

Developing and offering incentives that are both effective and feasible will require a concerted technical and constituency-building effort.

Immediate Action

The Commission recommends that:

- The Governor direct the California Office of Planning and Research to revise the State Planning Guidelines to address acutely hazardous materials and their relation to seismic hazards.
- The Governor direct the Resources Agency to amend the California Environmental Quality Act guidelines to improve the review of seismic hazards and risk-mitigation measures.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to:
  - Amend general plan laws to require that safety elements address the seismic vulnerability of the building stock, that elements be updated every five years, that they incorporate information published under the SHMA, and that the existing optional review of draft safety elements by the California Division of Mines and Geology be mandatory.
  - Amend the Alquist-Priolo Act and SHMA to allow designation of faults as active based on geologic, geodetic, and tectonic

Seismic safety is emphasized after earthquakes strike but is gradually pushed aside by other concerns.

evidence: to apply the acts to all publicly owned buildings, other facilities, and lifelines; and provide for alternative mitigation measures for buildings in areas of complex faulting and for lifelines.

- Amend the dam inundation mapping program to impose sanctions on dam owners who fail to prepare and submit maps by December 31, 1996, and to require updating of maps when downstream conditions change and review of maps every ten years.

Improving the Building Code Development Process

Although the current practice of relying on volunteers from professional organizations to draft and revise building codes has worked fairly well in the past, the state should fund some of the effort to make the process faster and to define accountability. The Commission believes the CBSC should be responsible for implementing and justifying the seismic provisions of the code to be enforced for all types of buildings statewide:

- It should review code changes proposed by others and, when necessary, propose new code language.
- It should identify weaknesses in the knowledge base supporting both the existing code and proposed changes and in some instances obtain and allocate funds for testing to substantiate the code.

A relatively modest level of annual funding to improve the code development process could make a significant difference in the effectiveness of the building codes in limiting earthquake damage.

Legislation

The Commission recommends that:

- The Governor support legislation during the 1995 session of the Legislature to designate the CBSC as the entity responsible to ensure that building codes and their administrative provisions meet the state's acceptable levels of seismic risk, ensure the adequacy of seismic safety requirements in the codes, and develop and adopt amendments for statewide application.

Supporting Focused Research

Every damaging earthquake reveals weaknesses in current practices and brings out new ideas to reduce risk. During the preparation of this report it was clear that focused research in engineering, geology, construction technology, and other areas was needed to answer specific questions raised by the earthquake. These issues also are contained in the Commission's *Research and Implementation Plan for Earthquake Risk Reduction in California* (SSC 94-01), a long-term plan for focusing research on California's pressing needs. The plan recognizes that applied research is an integral part of earthquake risk reduction and that the present level of funding is not commensurate with the need for information. The plan proposes establishing a Center for Earthquake Risk Reduction to manage the effort. A similar center was envisioned, but never funded, by Legislation enacted in 1986.

Legislation

The Commission recommends that:

- Legislation be enacted to create and fund a state-level Center for Earthquake Risk Reduction to implement a seismic safety research program.

Improving State Seismic Programs

The success of many of the recommendations in this report, as well as ongoing state-level programs, depends on the commitment and capabilities of responsible agencies. Because responsibility for decisions involving earthquake risk is often diffuse and vague, authority lacking, accountability missing, and resources—people and funds—inadequate, agencies may not be effective.

The Commission believes that to overcome these shortcomings, each agency should adopt measurable seismic safety objectives and a plan to meet them. The plan should have clear assignments of

responsibility and assessments of the adequacy of authority, knowledge, and resources needed to meet the objectives. Each agency should allocate the funds necessary, employ technically competent professionals, and commit to a system of external accountability.

These agencies and the responsible employees must be empowered to meet their seismic safety objectives. Oversight by persons with broader responsibilities and by control agencies is essential, but this oversight should be aimed at helping those responsible to do their job; it should not delay action. Disagreements regarding funding levels, qualifications of employees, and contracts must be resolved quickly. Seismic safety must be afforded the same level of importance as are other public-safety and fiscal matters.

Each state agency with the authority to design and construct facilities should be required by statute to meet earthquake performance objectives consistent with the recommendations of the "Colloquium." They should be required to use:

- Properly credentialed and experienced design professionals.
- An independent peer review of all important or complex structures and of designs for less complex structures that will be repeated.
- Independent plan checking by credentialed and trained individuals.
- Thorough construction inspection.

Lacking this explicit direction, public works programs may provide safe facilities most of the time, but to provide structures capable of the desired earthquake resistance consistently, these requirements should be adopted into law.

Raising earthquake safety matters to a higher level requires that the state's earthquake programs receive and use state-of-the-art information. Seismic matters require professional judgment that cannot be held by just one person or one organization. Agencies with focused missions, little flexibility in hiring and training specialists, and limitations on their ability to participate in nonagency efforts can benefit from the advice of outside, independent experts. The Commission believes each agency responsible for earthquake programs should incorporate independent peer review as part of its program. The findings of the peer review should be reported to the highest levels in agencies.

Immediate Action

The Commission recommends that:

- The Governor direct each state agency with the authority to design, construct, and lease facilities and those with responsibility for seismic safety programs, to:
  - Report to him on how seismic safety will be afforded priority attention.
  - Incorporate ongoing independent peer review on all seismic matters, including planning and priorities.

  Each report must include a plan, a schedule for implementation, a request for the financial and personnel resources to carry out the program, and an external reporting mechanism to ensure progress. Though the initial reports should be required by executive order, the State Administrative Manual should be revised by January 1, 1996, to incorporate requirements for plan contents and procedures for periodic review. The reports should be discussed with the Joint Legislative Budget Committee and reviewed and approved by the Department of Finance prior to being submitted to the Governor.

Markedly better earthquake performance can be achieved at minimal additional cost.

Role of the Seismic Safety Commission

The Seismic Safety Commission should continue to bring to state government the knowledge and views of the professions, local government agencies, and organizations responsible for seismic safety. It should continue to advise the Governor and Legislature and state and local agencies. It should continue to advocate improved earthquake risk-reduction and risk-management efforts, monitor progress, and report to the Governor, the Legislature, and the people of California.

Since 1985, California's laws have called for the state to reduce earthquake risk significantly by the year 2000. The California Earthquake Haz-

ards Reduction Act of 1986 mandates initiatives to meet this goal. The initiatives, published as a report titled *California at Risk: Reducing Earthquake Hazards 1992-1996,* provides the framework to organize, promote, and monitor the needed improvements to policies and identifies the responsible government and private entities.

In 1995 the Commission intends to launch an effort to focus this program, using the results of this study and other lessons from the Northridge earthquake. This program needs stronger backing to ensure identified organizations are accountable to their tasks. For example, at the time of the Northridge earthquake, 35 of 42 initiatives were behind schedule. Because seismic safety programs are a secondary concern for most agencies, these initiatives often do not receive the priority needed.

California law calls for the state to reduce earthquake risk significantly by the year 2000.

The deaths and injuries, damage, and economic disruption caused by the Northridge earthquake lend a new urgency to finding the funding necessary to finance the initiatives in *California at Risk* so that we can begin to act on our most pressing needs. The 1994 update of *California at Risk* identifies ten high-priority initiatives on which the Commission decided to concentrate its efforts and resources. All ten of those initiatives are still valid and critical to reducing earthquake risks statewide. Advancements on any of those initiatives will not only provide an immediate and direct benefit to the earthquake damaged area but will serve as a model for other jurisdictions to implement similar programs and, most important, further the overall goal of *California at Risk* by significantly reducing earthquake risks by the end of the century.

Conclusion

Earthquakes and damage are inevitable. More earthquakes like Northridge and possibly a major earthquake reminiscent of San Francisco in 1906 will strike before California significantly reduces its seismic risk. However, California can be better prepared and less vulnerable tomorrow than it is today. Successfully implementing these recommendations will improve management of earthquake risk and turn the losses from the Northridge earthquake into California's gain.

The Commission recommends that the Governor pursue the recommendations in this report, direct agency actions through executive orders to initiate the plans and programs where sufficient authority already exists, support a legislative program by sponsoring legislation to redirect authority and provide funds needed to carry out selected programs. The Governor should call on the federal government and private-sector organizations to help carry out the actions recommended.

The Commission believes that the effort needed to lay the necessary foundation to make seismic safety a priority can be completed, that the legislation needed can be enacted, and that the new efforts and incentives can be initiated by December 31, 1998. Investing in seismic safety is an investment in the future. The risk-reduction efforts that follow these foundation-laying efforts will continue for decades and create a cumulative and dramatic effect: lower earthquake losses in the future.

Glossary

abutment a support at the end of a bridge.

acceleration the rate of change of velocity of the ground or building in motion during an earthquake, commonly measured in terms of "g"—the increase in velocity of a free-falling body under the influence of earth's gravity (approximately 32 ft/sec/sec or 980 cm/sec/sec).

acceptable (risk) amount or level that can be endured or allowed. The question of whether a risk is acceptable must be gauged against some standard of what is deemed to be adequate by a particular individual or group at a particular time. Acceptable risk can be set forth as public policy through laws or regulations.

active fault used for maps prepared under the Alquist-Priolo earthquake fault mapping program. A fault that has ruptured the ground surface during the last 11,000 years is considered active. More generally, an active fault is one that has ruptured or is moving as part of present tectonic environment.

alluvial sedimentary deposits made by streams on river beds, flood plains, and fans.

amplitude the maximum height of a wave crest or depth of a trough.

ATC Applied Technology Council.

attenuation the reduction in the amplitude of a wave over time or distance traveled.

AWWA American Water Works Association.

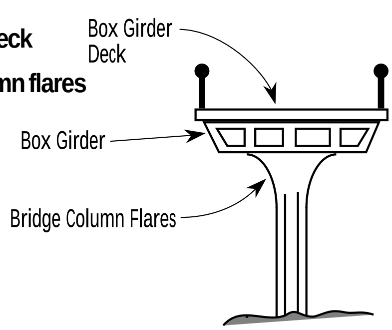
blind thrust a buried thrust fault.

BORPELS State Board of Registration for Professional Engineers and Land Surveyors.

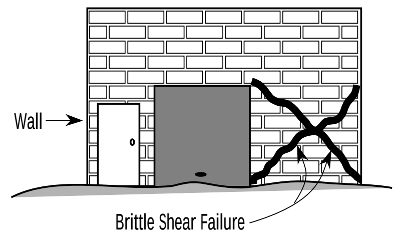
box girder

box girder deck

bridge column flares



brittle shear failures x-shaped cracks in masonry or concrete walls, columns, or beams.



BSSC National Building Seismic Safety Council.

building designer an unlicensed technician or subprofessional that may design conventional wood-frame structures.

buried fault a fault that does not extend to the ground surface.

CalOSHA California Occupational Safety and Health Administration.

CBSC California Buildings Standards Commission.

CDMG California Division of Mines and Geology.

CEQA California Environmental Quality Act.

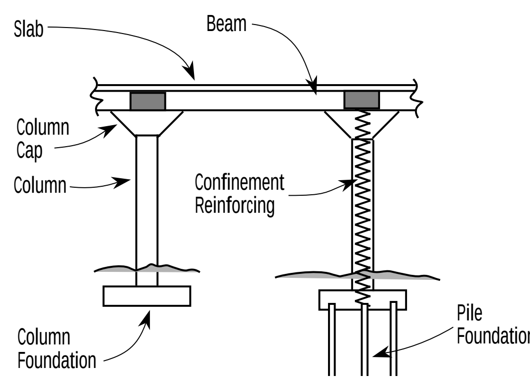
CHP California Highway Patrol.

code force level simplified design criteria for minimum earthquake resistance defined in the Uniform Building Code.

column cap

column foundation

confinement reinforcing



conventional construction wood-frame dwellings in regular configurations with 2x4 or 2x6 stud walls and not more that two stories and a basement.

COPR California Office of Planning and Research.

coseismic occurring simultaneous with an earthquake.

cripple wall a short wooden stud wall used on top of the exterior foundation to support the weight of a house and create a crawl space.

CSU California State University.

CUEA California Utilities Emergency Association.

CUREe California Universities for Research in Earthquake Engineering.

dangerous building see "unsafe building."

deck loading the car and truck loads used to design or evaluate a bridge deck and its supports.

design earthquake the theoretical earthquake and its associated shaking used to establish design standards for structures—typically an earthquake whose shaking has only a 10 percent chance of being exceeded in 50 years.

design professional a licensed architect, civil engineer, or structural engineer.

design response spectrum a method of characterizing a design earthquake for use in dynamic analysis for a range of structural periods of vibration.

design specifications the criteria for the design of a structure.

design-build procedure contracting method whereby the designer is hired as part of the builder's team.

designer of record the design professional who has signed plans to indicate that he or she is responsible for their overall adequacy.

deterministic design method a process in which one or more earthquakes are selected as the target for designing an earthquake-resistant structure. The target earthquake is usually selected by considerations of the historical seismicity record and physical characteristics of the seismic sources. Various characteristics of the target earthquake are then described in specific terms (for example, magnitude and peak ground motions). The deterministic method does not consider the likelihood of the occurrence of the target earthquake, nor does it offer any insight into the importance of the target earthquake compared to other possible seismic hazards, such as those that could be caused by smaller but closer earthquakes or larger but more distant earthquakes. Also see "probabilistic design method."

diaphragm a horizontal or nearly horizontal bracing system, such as a floor or roof, acting to transmit lateral forces to the vertical force resisting parts of a building.

displacement the distance a point on the ground is moved during an earthquake.

DSOD Division of Safety of Dams—a division of California Department of Water Resources.

duration length of shaking during an earthquake, measured in seconds.

dynamic analysis a method of evaluating a structure's response to ground motion that accounts for its natural tendencies to vibrate.

earthquake fault zone as used on Alquist-Priolo earthquake fault maps, it is a zone 500 feet wide on both sides of an active fault.

EERI Earthquake Engineering Research Institute.

effective peak acceleration reduced levels of acceleration after spikes of high-frequency acceleration have been truncated to account for the effect that rigid foundations tend to screen out very high frequencies recorded in free-field ground motion.

EIR environmental impact report.

elastic spectra more than one design response spectrum for structures that respond to ground shaking without damage.

engineer of record see "designer of record."

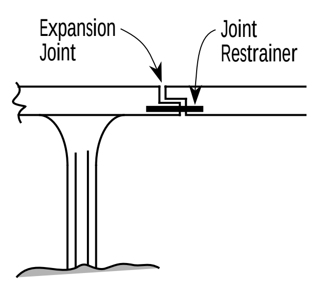
engineered fill earth fill designed by an engineer.

epicenter the point on the earth's surface directly above the focus of an earthquake.

ERB system earthquake resistant bracing system—an anchoring system, bracing system, or other device designed and constructed, or represented as having been designed and constructed, for the purpose of protecting the health and safety of the occupants of and reducing damage to a mobile home or manufactured home in an earthquake.

essential services building any building that is used or designed to be used as a fire station, police station, emergency operations center, California Highway Patrol office, sheriff's office, or emergency communication dispatch center.

expansion joint a gap in a structure that allows it to expand and contract with hot and cold temperatures.

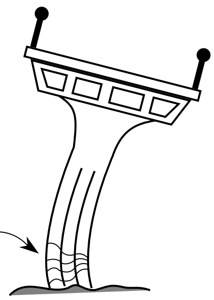


fault a fracture in rock along which there has been an observable amount of displacement.

fault rupture the breaking of the ground along a fault during an earthquake.

FEMA Federal Emergency Management Agency.

flexural failure the manner in which a structure loses strength and stiffness by bending during an earthquake.



focus the location (underground) at which fault rupture commences.

fold a bend in rock.

fracture zone a zone in which fault rupture has taken place.

free field a site with recorded groundshaking that is not influenced by the shaking of structures.

frequency number of vibrations per second.

functional-evaluation level a design specification that is intended to maintain a structure's ability to function after an earthquake.

general plan a city or county plan for the physical development of the jurisdiction.

geodetic data measured movement of the earth's crust.

geomorphic indicator land form that indicates the presence of a fault or faults.

geomorphology the description and interpretation of land forms.

geophysical data information gathered from a specified area—physical properties and relationships unique to the area mapped by one or more methods.

girder a horizontal structural member that spans supports.

green tag a placard that describes a post-earthquake safety evaluation of a building that is safe for occupancy.

ground deformation permanent alteration of the ground surface.

ground displacement the distance a point on the ground moves during earthquake shaking.

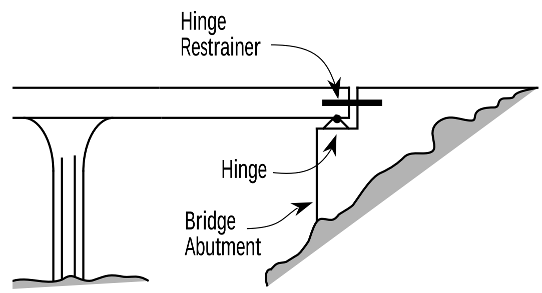
hardening generally no longer used—includes retrofitting, strengthening, or bracing to resist earthquakes.

hazard a natural phenomenon, such as shaking or ground deformation (liquefaction, landslides, and settlement), resulting directly or indirectly from earthquakes that can cause injury or harm. Buildings that might collapse are structural hazards; light fixtures, shelving, and sprinkler systems that might fail are nonstructural hazards.

hazardous building a building that a qualified professional has determined to have a high likelihood of posing a significant threat of death or injury from total collapse, partial collapse, falling hazards, blocked passages, or the release of hazardous materials in the event of a major earthquake. Hazardous buildings are not so unsafe as for governments to preclude occupancy.

HCD Department of Housing and Community Development.

high-deposition electrode a tool that welds steel members of a structure quickly.



hinge a bridge support that allows ends of girders to rotate.

hinge restrainer a bridge design or retrofit measure that keeps hinges from spreading apart too much during shaking.

historic building any building deemed important to the history, architecture, or culture of an area as determined by an appropriate governmental agency.

HUD Department of Housing and Urban Development.

HVAC heating, ventilation, and air conditioning.

ICBO International Conference of Building Officials.

inspection review of construction in progress to ensure compliance with approved plans and specifications.

intensity a measure of ground shaking obtained from the damage done to structures, changes in the earth's surface, and reports of persons' experience of the shaking.

JCAHO Joint Committee on the Accreditation of Healthcare Organizations.

joint restrainer a bridge design or retrofit feature that keeps bridge joints from spreading apart too much during shaking (see "expansion joint").

joists small beams supporting a roof or floor.

landslide the perceptible downward sliding or falling of a relatively dry mass of earth, rock, or mixture of the two.

landsliding the occurrence of landslides in an earthquake, often carrying buildings, trees, and roads along with it.

lateral slip horizontal movement along a fault.

lateral spreading sideways movement of earth materials and overlying structures during an earthquake.

lateral force path the sequence of elements and connections in a structure that is meant to carry and distribute side-to-side forces.

lateral force resisting system the part of the structural system assigned to resist side-to-side forces.

left lateral fault a strike-slip fault on which the displacement of the far block is to the left when viewed from either side.

licensing board term used for boards of registration in the Department of Consumer Services such as the Board of Registration for Professional Engineers and Land Surveyors, Board of Architectural Examiners, Board of Registration for Geologists and Geophysicists, and Contractors' State Licensing Board.

life safety the building performance objective that is the primary basis for building code requirements.

lifelines services that are vital to the health and safety of the community and the functioning of an urban industrial society (electric power lines, water lines, gas lines, roads, communication channels, railroads).

liquefaction the process that occurs when earthquakes shake loose, wet, sandy soil so it loses strength, allowing building foundations to sink or sloping ground to move laterally.

magnitude a measure of an earthquake's size in terms of the energy released.

major engineered buildings large, complex buildings that have been designed by architects or engineers.

microseismicity the occurrence of small-magnitude earthquakes.

minimum-performance bridge a bridge for which failure or loss of function would have acceptable consequences after a design earthquake.

moderate earthquake earthquake between magnitudes 5.5 and 7.0.

moment magnitude (M_W) a measure of earthquake size in terms of the leverage of the forces across the area of the fault slip. The rigidity of the rock times the area of faulting times the amount of dip.

mutual aid cooperation among government agencies to provide resources to a stricken agency in a disaster.

near field a mathematical term describing the shaking associated with a propagating wave. It is determined by analyzing seismograms recorded close to a fault.

near-source area the area of the ground surface lying above and adjacent to the fault plane. Its horizontal extensions from the fault are about the same as the depth of the rupture on the fault. When the fault is inclined, the area on the ground surface is described by the vertical projection of the fault plane to the surface plus depth-related extensions. In instances where the fault does not break the ground surface, the near-source area also includes the ground surface lying above the extension of the fault plane to the surface. The ground surface in the near-source area generally will be warped permanently by the movement of the fault.

near-source effects ground motion in the near-source area is characterized by high accelerations, pulses of large velocity, and permanent tectonic displacement. The nature of ground motion is related to the direction and mechanics of the fault rupture as well as the path of the seismic wave to the surface. The characteristics of near-source shaking do not follow the "normal" attenuation relationships used to describe shaking at more distant points.

NEHRP National Earthquake Hazards Reduction Program.

NIBS National Institute for Building Standards.

NOAA National Oceanic and Atmospheric Administration.

nonductile brittle, prone to sudden instability, loss of strength, stiffness, failure, and collapse.

nonductile concrete frame concrete beams and columns used in structures built before 1973.

nonlinear response the way a building reacts to ground shaking.

nonstructural elements referring to ceiling, mechanical, electrical, and architectural building elements.

nonstructural hazard nonstructural elements that might fail in an earthquake.

OASIS Operational Area Satellite Information System—a statewide emergency management information system.

occupiable referring to a structure that can be occupied without excessive risk to life after a disaster.

OSHPD Office of Statewide Health Planning and Development.

out of plane perpendicular to a wall.

out of plumb not straight up and down, skewed, or distorted.

peak acceleration maximum rate of change of velocity during shaking.

peer review review by professionals with similar expertise in a specific subject area.

performance objectives what an owner wants his or her building to achieve during a design earthquake.

period the time interval between crests in a wave pattern.

permanent ground deformation a general term for the process of making folds in rocks—the faulting, shearing, compression, or extension of rocks as the result of various earth forces.

phase velocity the velocity with which an observable wave or wave crest is propagated through a medium—the product of wavelength and frequency.

pilaster column embedded in a wall.

pile foundation a steel, wood, or concrete element driven down through earth to provide support for a structure (see "column cap").

plan check review of construction plans for conformance with the code.

plan review same as plan check.

portable classroom manufactured building for educational purposes.

post-tensioned tightened after concrete has cured and hardened.

posting placing a warning placard or notice on a hazardous, potentially hazardous, unsafe, or dangerous building. Notices on hazardous or potentially hazardous buildings should warn those who enter or pass nearby of the risk that the building presents; those on unsafe or dangerous buildings should prohibit entry as well as warning passersby.

potentially hazardous building a building that is one of a general type that has historically performed poorly in earthquakes and can pose a significant threat of death or injury from total collapse, partial collapse, falling hazards, blocked passages, or the release of hazardous materials in the event of a major earthquake.

prereduced spectra response spectra that have been reduced for a specific design criteria.

precast concrete plain or reinforced concrete element cast in other than its final position in the structure.

pressure ridge active small folds in rock related to tectonic pressure.

prestress condition losses reduced tension in steel due to slip, creep, and elastic shortening.

prestressed concrete reinforced concrete in which internal stresses have been introduced to reduce potential tensile stresses from loads.

probabilistic design method analysis of the earthquake hazard that addresses the questions of how strongly and how often the ground will shake by considering all possible earthquakes that might affect the site. The range of ground motions at a site resulting from earthquakes that might occur on a variety of seismic sources is estimated by using an attenuation function to translate to the site through distance the ground motions associated with earthquakes that are considered. The rate of earthquake occurrence on each seismic source is also considered. Also see "deterministic design method."

probability a quantitative description of the likelihood of an event occurring (for example, a hazard). Probabilities are derived by statistical methods. For example, the chance of a coin toss coming up heads is expressed as 50 percent, 50-50, or 1 in 2; all three expressions represent the same probability. Hazards, risks, and vulnerability are usually expressed and discussed in terms of the probability over a period of time. Frequently, the probabilities of earthquakes on different faults in an area are combined to determine the overall probability of earthquakes of a certain magnitude occurring in a given area. For example, geologists believe that there is a 67 percent chance that a magnitude 7 or greater earthquake will occur on one of the three major faults in the San Francisco Bay Area in the next 30 years.

PUC Public Utilities Commission.

purlins see joists.

quality assurance program a plan to maintain minimum levels of construction quality.

red tag a placard that describes a post-earthquake safety evaluation for a damaged building that is unsafe to enter or occupy.

relocatable classroom manufactured building on a temporary foundation. Also see "portable classroom."

residual stress internal stresses in building elements left over from a manufacturing or erection process.

response spectra graph showing how a range of structures will respond to given ground motions.

retrofit to strengthen, brace, remove excess mass, or otherwise reduce or alter the seismic response of existing structures.

return period the frequency with which a natural hazard can be expected to occur. This term is often misunderstood. If an earthquake of a specified magnitude on a particular fault has a calculated return period of 500 years, it means that, on average, over a very long period, the event will occur once every 500 years. It does not mean that events of the same or an even larger magnitude cannot occur more frequently than once in every 500 years or that other nearby faults will not have similar earthquakes. It does not preclude such events' occurring twice or more within a short time as happened in the San Fernando Valley between 1971 and 1994. Since many locations are threatened by several faults, the return period for strong shaking can be much shorter than the return period for an earthquake on a specific fault.

reverse fault the rock above the fault plane (hanging wall) moves up and over the rock below (foot wall). See Figure 10.

right lateral fault a strike-slip fault on which the displacement of the far block is to the right when viewed from either side.

Riley Act law requiring state and local governments to issue building permits and to inspect building construction.

risk exposure to a hazard and the probable outcome of combining a given hazard and a given vulnerability. The level of risk can be described as the probability of a specified loss over a given time. All Californians are exposed to earthquake hazards and are therefore at risk, though their individual levels of risk vary considerably.

roof screen a wall intended to shield roof-mounted equipment from view.

SAC Joint Venture a joint venture involving the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering.

safety-evaluation level a design specification that intends to maintain life safety but tolerates damage during earthquakes.

sag pond ponds occupying depressions along active faults.

sand boil extrusion of sand onto the ground through fractures produced by earthquake shaking.

SEAOC Structural Engineers Association of California.

Secretary for State and Consumer Services a member of the Governor's Cabinet responsible for the State and Consumer Services Agency.

seiche an oscillation of a body of water in an enclosed basin.

Seismic (base) isolation a method of decoupling or isolating structures from their supports to reduce the transmission of ground motions to structures.

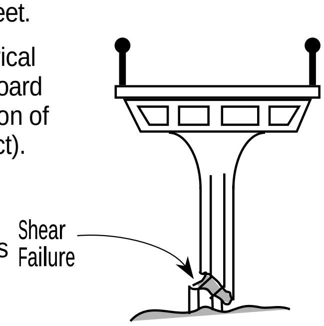
Seismic Hazards Mapping Act a statewide seismic hazard mapping and technical advisory program to assist cities and counties in fulfilling their responsibilities for protecting the public health and safety from the effects of strong ground shaking, liquefaction, landslides, or other ground failure hazards caused by earthquakes.

SFM Office of the State Fire Marshall.

shallow fill graded earth material used to raise or equalize the level of the ground, but limited in depth to several feet.

SHBSB State Historical Building Safety Board (within the Division of the State Architect).

shear internal stress in building elements that creates diagonal tension and compression.



shear failure the manner in which a structure loses strength and stiffness through diagonal tension and compression during an earthquake.

shear wall a wall designed to resist lateral forces parallel to the plane of the wall (sometimes referred to as a vertical diaphragm).

shell construction thin-walled elements used to form structures.

shotcrete pneumatically applied concrete.

sill plate the wood wall member that rests on a foundation.

single-column pier one tall, slender vertical bridge support.

slab a thin, horizontal structural element.

slump the downward slipping of a mass of rock or unconsolidated material.

SMIP or CSMIP California Strong Motion Instrumentation Program (Division of Mines and Geology, Department of Conservation).

SoCalGas Southern California Gas Company.

spread footing a foundation that supports structural loads by bearing on soil.

strike-slip fault a fault whose displacement is entirely horizontal.

structural engineer a civil engineer with a minimum of three additional years of experience in structural design and with successful completion of a 16-hour examination administered by the Board of Registration for Professional Engineers and Land Surveyors.

structural hazard structural elements, such as beams and columns, that might fail in an earthquake.

subsidence settling of the ground surface downward without moving sideways. Subsidence can occur during an earthquake when the underlying soil consolidates from shaking.

subtle fault faults with evidence of recent displacements and deformations that have been hidden by geologic processes such as erosion by wind and water.

supporting abutment a structure at the approach to a bridge.

surface fault rupture a fault that breaks the surface of the earth.

tectonic large-scale deformation of the outer part of the earth's crust resulting from forces in the earth.

tectonic compression compression caused by tectonic forces.

thrust fault a reverse fault that is characterized by a low angle of inclination with reference to a horizontal plane.

tilt-up a building with concrete walls cast on a slab at the building site and then raised into place.

Title 24 California regulations that include the building code and all state amendments to the code.

Title Act State law that authorizes licensed professionals to use a particular title.

topography the general configuration of a land surface, including its relief and the position of its natural and fabricated features.

tsunami earthquake-caused water wave.

UBC Uniform Building Code.

UC University of California.

UCLA University of California at Los Angeles.

uncertainty the condition of having a degree of unreliability. Probabilities that are derived statistically depend on the amount and accuracy of the data being used; the smaller the amount of information or the more inaccuracies, the greater the uncertainty. Simple probability analyses of a coin toss have little or no uncertainty; complex probability statements for earthquakes have significantly larger degrees of uncertainty. Thus, actual probabilities or return periods are somewhat uncertain and may be considerably higher or lower than the calculated estimate.

unsafe building a building that has conditions or defects described as "structurally unsafe or not provided with adequate egress, or which constitutes a fire hazard, or [is] otherwise dangerous to human life" (Uniform Building Code, Sect. 102, 1991 ed.). Dangerous buildings are further defined in Section 302 of the Uniform Code for Abatement of Dangerous Buildings (1991 ed.). These buildings are unsafe to occupy.

URM unreinforced masonry building.

URM infill non-load-bearing unreinforced masonry that is supported by frames.

velocity measured in inches or centimeters per second, refers to the rate of ground motion.

vulnerability a measure of the adverse consequences that might occur to an object as a result of exposure to a hazard, usually expressed as a probability of failure or collapse from a specific level of shaking in an earthquake. A building or other structure that may not withstand a level of shaking to which it may be exposed is vulnerable. Given the same hazard exposure, weaker buildings are more vulnerable than stronger buildings.

waffle-slab floor a concrete structural system with square voids resembling a waffle.

weak story one in which the story's strength is less than 80 percent of that of the story above.

wedge fill shallow fill on a hillside.

wing wall a side wall projecting from a main wall.

yellow tag a placard describing a post-earthquake safety evaluation of a damaged building that is only safe for limited use.

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